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ACCOMMODATION AND CONVERGENCE IN VISUAL SPACE PERCEPTION

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I. THE PROBLEM

This investigation deals with one of the numerous problems of visual space perception; specifically, with the part played in the visual judgment of the distance of objects by the action of the ocular muscles. For objects 'within infinity,' which by optical convention means within six meters, accommodation and convergence vary in amount with the distance of the object. If it is to function as a distance indicator, the first requirement of any form of ocular adjustment or of visual experience is that it vary in a systematic way with distance. For objects within the range specified, accommodation and convergence satisfy this requirement. It remains, however, to demonstrate experimentally that in addition to this variation they *do* serve as indices of distance; it must be shown that actual distance perceptions check with the distances for which accommodation and convergence are set, or in some regular manner correspond with such settings.

In order to demonstrate this it is clear that all other visual factors serving as 'signs' of distance must either be eliminated or held constant. Theoretically it should be possible to eliminate all of these factors excepting the size and brightness of the target-object. Since size and brightness must obviously always be present, the problem becomes that of ensuring their constancy while varying the amount of accommodation and convergence, and observing the effect of these variations on judgments of distance.

II. HISTORY

Speculations concerning the role of the ocular muscles in visual space perception date back to Berkeley (**2**). While some rather

crude experimental work was done by Wundt, the more important investigations did not begin until a quarter-century later. For the purpose of illustrating the earlier methods and results, a review may begin with the experiment of Hillebrand (**5**), which furnished a basis for the work of several others.

His target was the sharp edge of a sheet of cardboard. The remainder of the visual field was an illuminated screen placed several yards away. The visual aperture was so fixed as to maintain a constant visual angle; there were no size changes, that is, as the target was moved toward and away from the eye of the observer. Distances within one meter were studied monocularly.

With this device Hillebrand and his followers found that perception of gradual movements of the edge was almost impossible. Abrupt changes in distance gave a mean difference threshold of 23 percent (of the initial or standard distance) with one group of subjects, and of 12 percent with another. A significant feature of this work is the fact that the target used did not supply an adequate stimulus to fixation. Such a straight edge does not possess the psychological requirements of a visual target. It is not well adapted to arouse the percept of a *figure* to be visually defined; it has more of the quality of mere ground. The perceptual factor is an important one in the operation of accommodation and convergence, as will later be emphasized; it is not enough to provide only the physical basis of fixation. Subsequent tests with Hillebrand's method showed that the ocular adjustments did not vary with the distance of the target, as he had assumed.

Bourdon (**3**) constructed lanterns with adjustable diaphragms, providing a target which appeared to the observer as a luminous disc. The diaphragms were so adjusted for different distances as to maintain a constant size of retinal image. With the lanterns placed side by side in a dark corridor observers were unable to discriminate an object at 20 meters from one at 2 meters on the basis of accommodation and monocular convergence (using the latter expression to designate the binocular convergence which occurs when only one eye is in use). Tests inside this distance, where disproportionately greater amounts of the two ocular adjustments are involved, were not made.

Bappert (**1**) continued the experiment of Bourdon for distances inside one meter. The targets again were luminous discs, in this case provided by cutting apertures in screens. Through the apertures a homogeneous ground was visible, sufficiently distant to conceal its surface detail. The observers were told to fixate the edge of the disc. As before, the size of the target was so related to its distance as to maintain constancy of retinal image size. The targets were presented

successively, in pairs, at the following distances: 16.5 and 25 cm; 25 and 50 cm; 33.3 and 100 cm. In each case the difference in distance corresponds to a change of 2 diopters of accommodation. There were 5 observers. In one-half of the trials no change in distance was reported. In 19 percent of the cases the judgments were correct; in 25 percent the distance change reported was the opposite of the actual change, and in 5 percent the subjects were undecided. Such data certainly do not favor Berkeley's suggestion that the movements of the eyes contribute to the normal accuracy of distance perception.

In striking contrast with these findings are those of the most recent study of the problem by Swenson (7) covering part of the same critical range of distances as that of Bappert—'critical' because if the ocular movements do exert any influence on distance perception the effects should certainly appear at such close range.

Swenson used a mirror stereoscope devised by Dr. H. A. Carr, of the University of Chicago. Its design was such as to make possible the systematic variation of accommodation and convergence, both together and independently. While differing from the two foregoing studies in that it provided binocular control of the adjustments of the eyes (Bappert's experiment was monocular), Swenson's method was similar in main essentials. Here again the target was a luminous circular surface, assumedly lacking in visual texture, and offering no size or brightness changes as its distance was varied. For different settings of accommodation and convergence the observer indicated the apparent distance of the target by moving a marker (itself unseen) until it was judged equidistant with the visual image. This distance was then measured. The range of distances selected for study was from 25 to 40 cm. Five subjects were used.

Surprisingly accurate perceptions of distance were recorded. The average error of the judgments, as compared with the distances for which accommodation and convergence were set, was less than 1 cm. When the two adjustments were set for different distances the judgments located the target at a point between them. For example, with convergence adjusted for 25 cm and accommodation for 30, the mean apparent distance of the target was 26.51 cm. With convergence adjusted for 40 cm and accommodation at 25, the mean apparent distance was 36.95. From this it was concluded that both factors were effective, but that convergence had considerably greater potency in determining the apparent distance.

The weakness of studies using this type of target lies in the failure to appreciate the psychological factor in accommodation. The milk glass chosen for the target was intended as a perfectly homogeneous surface, free of any detail or markings which might

offer visual cues of approach and recession as the distance of the target was varied. Unfortunately, a perfectly homogeneous surface does not provide a stimulus to accommodation. This reaction, unlike such a response as that of the pupil to light, requires more than a certain kind of physical stimulation of the retina. It depends not only on a change of the wave-front of light but on a *perception of something to be seen.* A surface literally devoid of any figure or detail offers nothing for the observer to fixate. There could be no blur with changing distance of the target because there would be at outset no point to focus upon. Professor Carr has suggested that accommodation may be a more effective factor than the findings of this experiment would indicate, admitting that "Such a surface is not conducive to accurate accommodation, and hence the lens may not have been fully adjusted to the position of the light" (**3**).

Assuming that accommodation did occur in this instance the conclusion may be, as Woodworth has suggested (**8**), that the target was actually not free of markings or some degree of visual texture, and that these details functioned as cues of distance. Swenson's data may therefore be explained on the ground that only convergence was aroused in an effective way, and that the accuracy of the judgments made on this basis may have been aided by visual cues and by some degree of accommodation.

III. General Method

The distinctive feature of the present study lies in the method used for the control of image size and of the visual detail of the target. The advantage of this method is that it controls both of these factors by the same optical device. The target presents a definite figure, which supplies, as its distance varies, a thoroughly adequate stimulus to accommodation, but there is no corresponding change in size, brightness or detail.

The means providing this control was suggested by one of the demonstrations of geometrical optics. Briefly, if a lens is so placed before the eye that its principal focus coincides with the first focal point of the eye, ". . . the image formed on the retina will be of the same size no matter where (an) object is placed . . . in front of the lens . . ." (**6**). This statement is valid, however, only for a fixed refractive status of the eye during movements of the object seen through the lens. Since, obviously, the eye must accommodate as an essential part of the experiment, the conditions for image size-constancy as described above cannot be met. It is impossible, that is, to maintain an image of absolutely unchanging size on the retina in this way, since the process of accommodation necessary for a focussed image itself brings about a departure from the conditions essential to constancy.

On the other hand if it can be demonstrated that the changes in image size which would occur under these conditions are so minute as to be far below the threshold of sensibility, the principle still offers a practical solution of the problem. The task becomes then to ascertain what the total range of size changes will be under the conditions of the experiment, and to show that the greatest change possible is below the limen of discrimination. Calculations showed that the extreme range of these changes which could occur during accommodation, and depending on the precise position of the lens focus for eyeballs of various sizes, was from 1.5 percent per diopter down to zero. This work was checked by Dr. R. A. Fisher of the Department of Physics of Northwestern University, and by Dr. Weinberg, of the Department of Mathematical Biophysics of the University of Chicago. In a study of the discrimination of a 1.5 percent size change in 21 subjects, the proportion of reports agreeing with the objective changes was no

better than chance would account for. Since, moreover, so large a size change as this would rarely occur in the experiment proper, the size factor was regarded as being under adequate control.

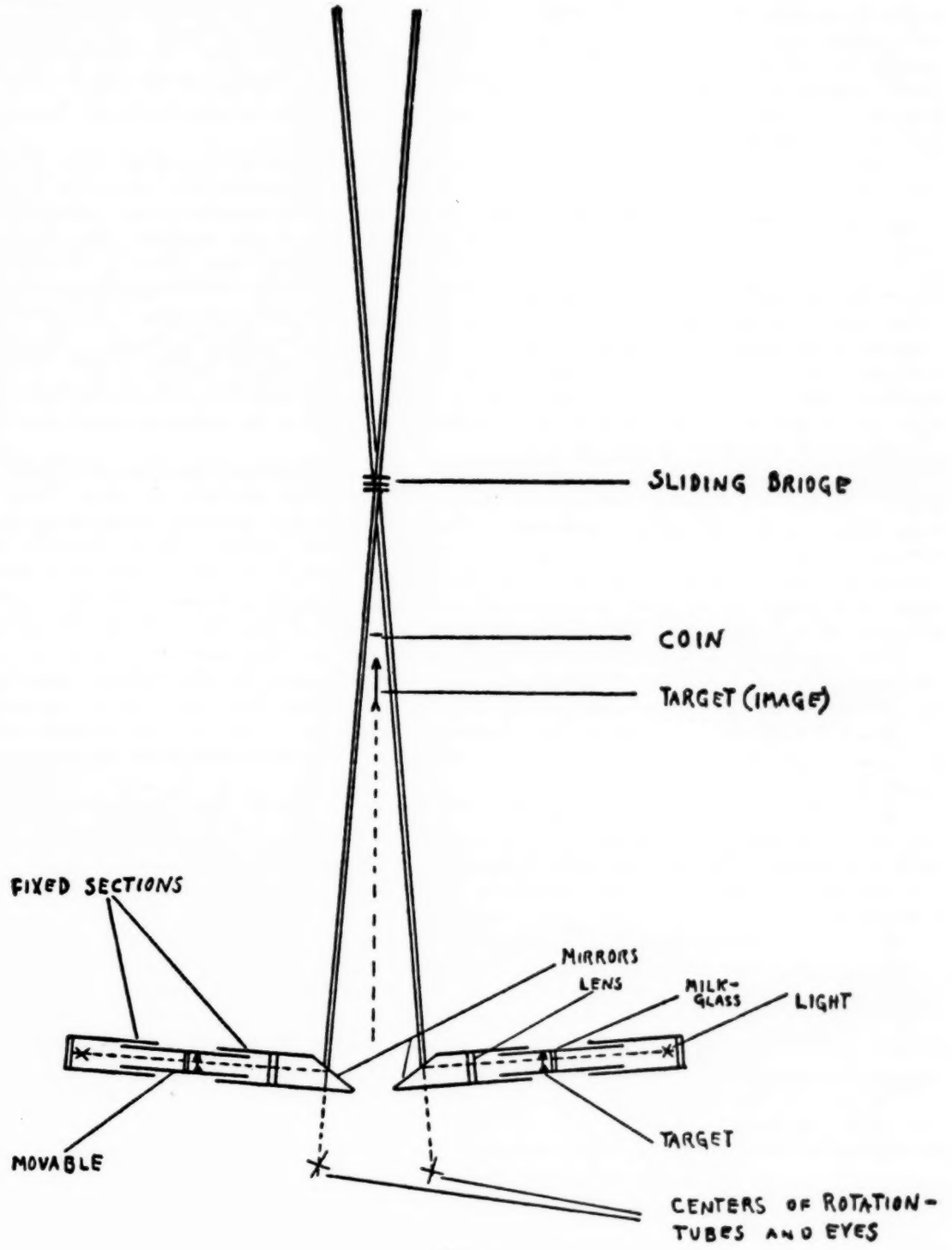

FIG. 1.

The experimental instrument, diagrammatically represented in Fig. 1, was designed by Dr. Carl F. Shepard of the Northern Illinois College of Optometry, and constructed by Dr. Galen F. Kintner, formerly of the same institution. The writer wishes to acknowledge his very great indebtedness to these colleagues, and especially to Dr. Shepard, without whose assistance the project might never have been attempted.

The apparatus consists of a pair of tubes which contain the binocular optical means for control of image size: the lens, the target, the illumination, and a screen of milk glass. The eyes are located at the positions indicated by the two crosses; the tubes thus project sidewise at right angles to the lines of vision. The target is seen as a mirror image through an aperture in the tube. Each tube is rigidly fixed to one of the long rods extending forward. The tubes are rotated by sliding a metal bridge forward and backward over these rods. By this means the angle at which the mirrors reflect the targets into the eyes may be varied, the degree of convergence being controlled in this way. In order to maintain fusion of the two images the eyes must adjust precisely to the angle of reflection.

The single binocular image is seen projected forward into space in the midline between the rods. In one mirror is a pinhole through which a coin is seen suspended over the mirror image in the same midline. This coin, illuminated by a shielded bulb attached to the coin-holder, slides toward and away from the observer along a rod not shown in the drawing. The distance of the coin from the observer's eyes may be read from a meter stick hung above it. The coin, chosen for the familiarity of its appearance, is used as the indicator of the apparent distance of the target. When aligned with the target by the observer, its distance serves as an objective measure of the location of the target in space. The coin was never directly fixated. The eyes were kept upon the target at all times, the coin being seen by slightly indirect vision. Since, moreover, the coin was viewed only by 'pinhole vision,' *i.e.* by approximately parallel rays of light, the experimental variations of accommodation determined by target movements were not affected by the movements of the coin.

The target itself consisted of a row of numbers printed in black upon a glass slide, being a section cut from an ordinary visual acuity test slide designed for use in a projector. Such a target offers a much more adequate stimulus to accommodation than the screen edges, suspended threads, and unfigured surfaces previously used in work on this problem. It was mounted in the lens tube upon plane glass, the latter then being covered with black tape around the number strip. It appeared to the observer as a vertical row of numbers on a luminous ground. Light was supplied by a flash-light bulb at the end of the tube, and diffused by a disc of milk glass.

The distance between the light source and the eye was fixed. With target movement toward the eye the cone of light passing through the target aperture would be infinitesimally reduced, the maximum target movement being only 2.5 mm. Reflection from the sides of the tube would tend to offset this reduction and favor brightness constancy. The possibility of fluctuation is thus extremely slight, and is in the direction of a reduction of brightness as the target moves *toward* the eye.

While a preliminary test was made with a single eye, the main data of this study were obtained binocularly with convergence under control as described. Fusion of the images was easily maintained in the great majority of cases. The tube containing the target was inserted by a key-and-slot fixture into that containing the lens, thus preventing any rotation during adjustments.

Not shown in the figure is a binocular eye-rest, removed from a clinical instrument, adjustable to different interocular distances, and made to fit into the sockets in such a way that the proper position of the eyes could be maintained independently of individual variations in the prominence of the brown. These socket-pieces were snugly fitted at the beginning of a series of observations, and this position was carefully ensured through the series both by instruction and by checks made by the experimenter.

The entire instrument with the exception of the eye-rests was covered with a hood of heavy black cloth to exclude any fluctuations in the illumination of the coin, and in general to eliminate any distracting visual impressions that might appear through the pinhole.

IV. Experimental Procedures and Results

Two methods of obtaining distance judgments were used, one somewhat similar to the method of 'minimal changes,' the other comparable to the 'constant' method. One was used to obtain non-quantitative judgments of the relative distance of coin and target; the other involved quantitative measurements of the absolute distance of the target.

The procedure in the case of the latter method was as follows. After setting accommodation and convergence for a certain fixation distance the experimenter moved the coin close to the nearer end of the rod to which it was suspended, and where it was perceived as very definitely closer than the target. It was then moved outward at a moderate, and as nearly as possible a constant, rate of speed. The subject, with eyes fixed on the target, signalled 'Now!' at the instant the coin appeared to be equidistant to it. The coin was then similarly moved inward from the farther end of the carrier and again stopped at the point of equidistance. A 'test' consisted of a pair of such judgments, one for the inward movement and one for the outward. In the binocular series by this method three such tests were made on each of thirty subjects, the individual finding then being the mean of the six readings. Accommodation and convergence were together set for three different distances: 50 cm, 33.3 cm, and 25 cm. The findings are summarized in Table I. Each of the three means given here was derived from the individual means of 30 subjects, the latter obtained as explained above.

TABLE I

	50 cm	33.3 cm	25 cm
Mean Apparent Distance	41.4	37.8	34.3
Sigma	5.2	4.5	4.4
Standard Error	0.94	0.82	0.80

Standard Error of Difference 41.4 − 37.8 = .525
C. R. = 6.8
Coefficient of Correlation between distributions at 50 and 33.3 cm = .83
Standard Error of Difference 37.8 − 34.3 = .472
C. R. = 7.4
Coefficient of Correlation between distributions at 33.3 and 25 cm = .83

In the second method of study accommodation and convergence were first set for 33.3 cm. The coin was then aligned with the target in the way described earlier. Occasionally additional small adjustments were made until the subject was satisfied with the impression of equidistance, although usually this was completed with the first signal. Following this the subject was instructed to close his eyes for a moment while the settings were changed to a new fixation distance.

These changes were of three kinds: (1) adjustments for both accommodation and convergence were set first for 50 cm, and then for 25 cm; (2) with convergence fixed at 33.3 cm accommodation was increased to 25 cm and reduced to 50 cm (*i.e.* increased and decreased by 1 diopter); (3) with accommodation fixed at 33.3 cm convergence was reduced to 50 cm for one judgment, and then increased to

25 cm for another. Following each of these changes the subject was instructed to fixate the target and to report 'Same,' 'Nearer,' or 'Farther' regarding its distance relative to the position of the coin.

The six settings, each of which followed an alignment of the coin and target with accommodation and convergence adjusted to 33.3 cm, were as follows:

Accommodation and Convergence at 50 cm
Accommodation and Convergence at 25 cm
Convergence at 33.3, Accommodation at 25
Convergence at 33.3, Accommodation at 50
Accommodation at 33.3, Convergence at 50
Accommodation at 33.3, Convergence at 25

The order of these settings was systematically rotated. There were 34 subjects, who gave 202 judgments. Table II summarizes the findings.

TABLE II

Under 'Judgments' the heading 'Right' means that the change in distance of the target reported was in accordance with the change in ocular adjustment: 'Nearer' with reduced fixation distance, 'Farther' with increased distance. A 'Wrong' judgment means a report, *e.g.*, that the target was seen farther away after the adjustment was changed to that for a nearer point. 'No. R' means no response, *i.e.* no difference in the distance of the target was perceived following a change in setting.

	Judgments		
	Right	No R	Wrong
Accom. and conv. changed together from 33.3 to 50 cm and from 33.3 to 25 cm... 54/68 = 80 percent correct.....	54	8	6
Conv. constant; accom. changed from 33.3 to 50 cm and from 33.3 to 25 cm..... 52/68 = 76 percent correct.....	52	7	9
Accom. constant; conv. changed from 33.3 to 50 cm and from 33.3 to 25 cm..... 48/66 = 73 percent correct.....	48	10	8

The data presented in Tables I and II comprise the central findings of this study. Before these were obtained a preliminary series of monocular observations was made, using one side of the instrument, in order to get an indication of the variability of the judgments, and also for the bearing these findings might have on the question of double images to be discussed later. With one eye in use accommodation and convergence occur binocularly, though to a lesser degree than is the case with binocular fixation. One test was made on each of 40 subjects. The means of the 40 judgments of apparent distance are given for two adjustments of accommodation

and convergence, one at 50 cm, the other at 25 cm. Table III presents the analysis.

TABLE III

	50 cm	25 cm
Mean Apparent Distance	49.9	45.4
Sigma	6.76	6.08
Standard Error	1.07	.96

Coefficient of Correlation = .84
Standard Error of Difference 49.9 − 45.4 = 0.583
C. R. = 7.7

The data of Table II indicate that the effects of the two ocular adjustments are about equally potent in determining distance judgments. The study of the relative influence of the two factors upon the apparent distance of the target, in Swenson's experiment, showed convergence to be from 2 to 5 times as effective as accommodation, but it will be recalled that the target used in this work admittedly did not provide an adequate stimulus to the arousal of accommodation. On the other hand the target selected for the present study was ideally suited to evoke a sharp focus, the figures being slender and well defined.

The evidence of Table II as to the comparative effects was experimentally checked in a different manner. A series of observations was made by the method of alignment with the moving coin in which the reactions were 'dissociated' or adjusted for different distances. Distance readings were taken with accommodation set for 50 cm and convergence at 25, and again with convergence set for 50 cm and accommodation for 25. Twelve subjects were used; 3 tests were made on each subject. Table IV summarizes the results.

TABLE IV

	Accom. at 50 cm Conv. at 25 cm	Accom. at 25 cm Conv. at 50 cm
Mean Apparent Distance	35.3	36.8
Sigma	4.88	5.24
Standard Error	1.41	1.5

Coefficient of Correlation = .89
Standard Error of Difference 35.3 − 36.8 = 0.70
C. R. = 2.1

In connection with the method of measuring apparent distance by the alignment of coin and target, the possibility was suggested that movements of the coin toward and away from the eye, preliminary to the movements made in gauging the distance of the target, might have exerted a 'dynamic' effect on the subsequent impression of distance. Accordingly a series of observations was made on 10 subjects by a slightly modified technique designed to discover whether there were any systematic effects that might be traced to this source. The change consisted simply of instructing the subject

to close his eyes until the coin was in proper position (either at the farther end of the carrier or at the nearer end) for movement toward the target. Each complete distance perception therefore involved no change in the character of size variation of the coin image, *i.e.* no reversal in the direction of the change of image size. An increase or a reduction of image size was continuous from the starting signal until the point of coincidence was reached. The position of the coin at the moment its movement was begun was also varied in a systematic way.

The results are tabulated below. The three headings (Table V) indicate the distances for which accommodation and convergence were set. Under each are given the two means obtained by the two methods of administration, the first of each pair being that obtained by the original method, the second that by the modified method.

TABLE V

	50 cm		33.3 cm		25 cm	
Mean	41.5	40.9	37.9	37.0	33.1	32.2
Sigma	5.2	6.2	4.8	4.5	5.5	5.9
S. E.	1.64	1.96	1.52	1.42	1.74	1.87

50 cm
Coefficient of Correlation = .89
Standard Error of Difference = 0.90
C. R. = 0.66

33.3 cm
Coefficient of Correlation = .96
Standard Error of Difference = 0.42
C. R. = 2.1

25 cm
Coefficient of Correlation = .76
Standard Error of Difference = 1.26
C. R. = 0.71

One further section of this study was prompted by an interest in the possible effect of postural tensions on the action of the ocular muscles. A group of observations was made involving two parallel series of judgments, one obtained in the usual way, the other modified by the fact that the subject pulled on a dynamometer with one hand while making his reports on target distance. These tests were carried out exactly like the others except that a signal was given the subject just before the coin began its movement toward the target. At this signal he pulled on the dynamometer and kept up the tension until he had given his own signal of target coincidence. Ten subjects were used, 6 judgments or 3 'tests' being obtained from each. Table VI gives the findings. As in the preceding table the means are listed in pairs under each heading (for distance), the first mean

being that obtained by the original method, and the second that for the experimental method, in this case tension.

TABLE VI

	50 cm		33.3 cm		25 cm	
Mean	40.4	39.4	37.4	37.2	35.5	34.3
Sigma	4.3	4.7	4.4	4.2	5.3	5.57
S. E.	1.36	1.5	1.4	1.3	1.7	1.8

50 cm
Coefficient of Correlation = .95
Standard Error of Difference = 0.48
C. R. = 2.0

33.3 cm
Coefficient of Correlation = .84
Standard Error of Difference = 0.77
C. R. = 0.26

25 cm
Coefficient of Correlation = .96
Standard Error of Difference = 0.51
C. R. = 2.3

V. Observations and Discussion

The first data obtained in this study were those of the monocular method. In this instance accommodation occurred in both eyes although directly stimulated in but one; convergence likewise is a binocular reaction under monocular stimulation. In this case, since the eye in use remained directed straight ahead upon the target during accommodative increase, the only associated convergent change involved the unused eye, whose axis rotated toward the nearer point for which accommodation was now adjusted. This associated reaction is well known and may be observed by shifting from far to near with a finger-tip upon the closed lid of one eye; the inward rolling of the corneal projection may easily be felt. However, under these conditions the adjustment of the unstimulated eye is seldom complete; the amount of convergence thus aroused varies in amount, on the average, from two-thirds to three-quarters of that required for perfect binocular fixation, while accommodation approaches somewhat closer to the amount needed for an adequate focus. The much more pronounced effects of the two reactions upon distance judgments in the binocular series may thus be explained by the fact that the normal stimulus was here supplied to *both* eyes, arousing maximum focus and accurate convergent fixation.

A further significance of the monocular data lies in their bearing on the possibility that double images might have contributed to the results of the binocular study. These images, as Woodworth has

pointed out, are impossible to eliminate from experiments of this kind involving both eyes. Assuming that the lines of vision of the observer's eyes are parallel or approximately so when he first puts them up to the eye-pieces, double images of the target would be present until by convergence they are fused together. The nearer the object, the greater the convergence required, and the greater the amplitude of movement of the images toward fusion. In thus changing systematically with the distance of the object fixated, the images meet the first requirement of a visual 'sign' of distance.

There are several reasons why this theoretical possibility may be regarded as having little weight in the present case. (1) The monocular tests show that accommodation and convergence can, without the aid of double images, produce thoroughly reliable differences in the distance of visual images. It seems consistent to suppose that the *greater* effect of these adjustments, owing to their more adequate arousal with binocular stimulation, is likewise the explanation of a merely more marked difference in the same direction. Again, while it is demonstrated that the muscle activities, in the absence of the images, have a definite effect upon spatial impressions, it has not, to the writer's knowledge, ever been experimentally ascertained that double images, in the absence of these muscle activities, mediate spatial judgments. They are often referred to simply as possible or probable cues. That apparently they could be does not, obviously, prove that they are. (2) Convergence and accommodation offered a *continuous* basis of distance perception, coinciding with the judgments themselves, while double images were present only for an extremely brief instant of the preliminary adjustment of the eyes, and before the test began. With an active distance cue available at the time the judgment was made, it seems surely unnecessary to believe instead that the judgments reported were really made earlier, before the images were fused, and were 'recalled' (?) at the time of the signal to the experimenter. It is contended here that the perceptions were made on the basis of present rather than past cues, and that they were continuous during single binocular fixation until the distance could be indicated, *i.e.* coincidence of target and coin reported.

(3) It has many times been asserted that we are habitually inattentive to double imagery. "Double images are not ordinarily seen. Many college students are wholly unaware of their existence until their attention is called to them. Double images are visible only when we actively look for them" (4). Such distance cues as superposition, shading, detail, etc., are quickly recognized by the student as soon as indicated, but some students, according to Carr,

". . . always experience considerable difficulty" in finding the images. It does not seem likely they could be in constant use. Nevertheless their presence, since they cannot be eliminated, must apparently be accepted as an inevitable limitation of this type of study, rather than as a defect in the control of visual factors. If double images are literally inseparable from convergence the matter of their relative influence on space impressions is hardly a vital issue.

Size of the Visual Image

While observations of change in size of the visual image during variations of accommodation and convergence were not a systematic part of the experiments described above, the question was put to about one-third of the subjects. Almost invariably the target was reported smaller when the adjustments were changed to those for a nearer position (fixation point), and usually, though not always, it appeared larger when fixation shifted to a farther point. 'Nearer and smaller,' and 'farther and larger' were the typical findings. They agree with observations of some of the early workers (Wheatstone, Judd) that with a constant size *retinal* image, increasing convergence results in a reduction of the size of the visual image. In nearly every instance this phenomenon was reported with certainty when accommodation and convergence were changed together, and likewise when convergence alone was changed. This was not true of accommodation alone, however, where many reported no change in size.

A series of observations was subsequently made of the effects of accommodation on image size. There were 17 subjects who furnished 51 judgments on the size of the target with increased accommodation and the same number for diminished accommodation. With increase there were, 27 reports of 'smaller,' 20 of 'no change' and 4 of 'larger.' (The percentages were 53, 39 and 8, respectively.) With diminished accommodation there were 6 reports of reduced size, 33 of no change, and 12 of enlargement (12 percent, 65 percent, 23 percent). Comparing these data with those of Table II it appears that size and distance changes are not closely associated in the case of accommodation.

'Reversals'

The fact that judgments occasionally occur (*cf.* Table II) in which, for example, the target may be reported as farther away with a change in accommodation or convergence or both for a nearer point may be interpreted as indicating that sporadically the effects of the muscle reactions were overcome by those of the change in

image size. Woodworth has advanced this suggestion in a similar context. So fundamental a distance cue as size change might be expected to offer competition with the effects of the fixative adjustments, especially since these effects are opposed to all previous experience: objects normally recede when they become smaller. The findings demonstrate, nevertheless, that with a constant retinal image the muscle changes are more potent than those of visual image size in the vast majority of trials, and considering the pooled data of both methods.

These reversals sometimes occurred as a 'first impression' when the eyes had just been opened for a new fixation, when the attention had not yet fully 'settled' on the target, and probably before a clear focus had been obtained. In such instances the subject first reported, *e.g.*, that the target was smaller and more distant than before, then suddenly changed his report to 'smaller and nearer,' the latter judgment being in accord with the new adjustment of the eyes. This second perception was typically stable; there were no further reversals. The fact that the reversal phenomenon seemed to be correlated with an attentive set not fully stabilized and probably with an incomplete fixative adjustment suggests that it might be expected more frequently with a target which did not provide a very strong perceptual stimulus, and which therefore would not fully arouse accommodation and convergence. The vigor and sharpness of these reactions depend primarily upon the interest awakened by the object fixated. This interpretation may be offered for the large number of reversals occurring in Bappert's experiment. His target, like most of the others used in these studies, was of rather indifferent perceptual value.

The statement made earlier that the reduced-size-reduced-distance relationship is 'opposed to all experience' does not, of course, imply that *increased* visual image size was to have been expected when the ocular adjustments for a nearer point in space were stimulated. The findings obtained are logical, granted the primacy of the effects of the muscles. If an object were to approach the eyes, arousing the normal fixative activities, yet casting an image of constant size on the retinas, it would necessarily have to undergo a corresponding reduction in physical size in continuous proportion to its distance. The present experiment set up the normal fixative activities for an approaching object together with artificial maintenance of an unchanging retinal image. The perceptual consequence of this was an image (visual) of diminished size and reduced distance—an impression in harmony, that is, with what the physical facts would have to be to provide such unusual stimulation.

The Displacement of the Judgments

The reason for the displacement of the means of the judgments obtained by alignment of the target with the moving coin (Table I) from the expected positions, approximating 50, 33.3, and 25 cm, is a question yet unanswered. The tendency of these deviations toward a point in the neighborhood of 40 cm led to the speculation that some factor associated with the habitual reading distance (which for most people is not far from this point) might have something to do with the matter. But the reading distances of 30 subjects were found to correlate practically zero with the central tendencies of their combined judgments of target distance. Work on this point may be resumed at a later date in a continuation of the present study.

VI. Summary

The effect of accommodation and convergence on distance perception, exclusive of the operation of other visual factors, was studied by means of an optical system providing unified control of image size and of the surface detail of the test target. Changes in the apparent distance of the target were measured and found to correlate in a systematic way with variations in the accommodative and convergent adjustments of the eyes. Reducing the distance for which these fixative reactions were adjusted caused the test object to appear closer: increasing this distance had the opposite effect on the impression of target location. The differences between the mean distance judgments of 30 subjects were found to be statistically reliable.

The same problem was approached by a series of observations in which the apparent distance of the target was varied by increasing and decreasing accommodation and convergence by a certain amount, the distance changes then being noted by comparison of the target with a fixed point of reference in space, unaffected by the ocular changes. A group of 34 subjects gave 202 judgments; the correct perceptions ranged from 73 percent to 80 percent, as compared with 33 percent correct by chance.

Reports on apparent size changes of the target showed that increasing accommodation and convergence not only reduces the distance but diminishes the size of the visual image, the space impression thus being the reverse of that normally associated with size reduction.

Two modifications of the experimental procedure, one involving the method of target movement, the other introducing muscle tension in an arm, were found to be negligible in their effect on distance perception.

The distinctive features of this experiment were:

1. We secured a more effective control of accommodation than has previously been achieved in work on this problem. The target selected took cognizance of the important perceptual factor involved in this reaction.

2. We obtained a much larger sampling of subjects than in any of the previous experiments.

3. We controlled the size and detail of the target by the same optical arrangement.

4. We devised a mirror-and-pinhole apparatus for obtaining quantitative measures of apparent distance on a visual basis.

5. Monocular as well as binocular tests supplied data which, along with other observations, tend to indicate that double images had little or no effect upon the findings.

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GENERALIZED CONDITIONED RESPONSES UNDER CURARE AND ERYTHROIDINE

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INTRODUCTION

The dissociation in behavior produced by curare was first reported by Girden and Culler (11). Learning established in dogs during curarization was repressed upon recovery but reappeared spontaneously when the animals were again subjected to the drug. Conversely, the conditioned response (CR) [1] developed in the normal animal appeared only in the normal state and never in the drug-state.[2] Preliminary electrical measurements indicated that while the sensitivity of the motor roots of the spinal cord under the drug remained the same or was even improved, the motor cortex was depressed. It was therefore suggested that, whatever the peripheral effects of curare, there was a cerebral depression such that the Curare-CR was subcortical in locus (medial geniculates, collilicus or lower) whereas the Normal-CR involved the cortex, in so far as the specific conditioning situation used in these experiments was concerned.

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[1] In order to conserve space, the following short-hand expressions have been used: B = bell. CS = conditional stimulus (B, L, L + B, T). CR = conditioned response. Diff. = diffuse, generalized activity of the body, tail, head, neck, etc. The exact form varies, depending upon the depth of the drug-state. DMR = direct muscle response, appearing in the very deep drug-state, in which the block at the myoneural junction is complete. The muscle will, however, still contract to the direct action of the shock upon the muscle fibers (*cf.* footnote 7 below). L = light. L + B = L presented for 4 secs., overlapped with B for the last 2 secs. P = pupil of the eye. ST = semitendinosus muscle. T = pure tone, 1024 cycles, 90 db., generated by Western Electric audiometer. UR = unconditioned response. US = unconditioned stimulus, shock. CR training scores are represented in fractions; the numerators denote the number of CR and the denominators give the total number of trials.

[2] During tests in the drug-state, there was only a partial block to nerve impulses at the junction between motor nerve and muscle. Thus the isolated muscle was still capable of some degree of contraction, although the quality of the response was apparently different. The rest of the musculature remained completely inert during these tests. With larger doses, of course, even this action could be suppressed.

This original hypothesis was confirmed by two subsequent studies. Further measurements of the sensitivity at the spinal cord and motor cortex (**4**) agreed with the preliminary electrical results originally reported. A functional check was also devised by establishing the normal and drug conditioning in animals after the bilateral removal of the auditory cortex of the brain (temporal lobes). Since the conditional stimulus was auditory, both Normal-CR and Curare-CR necessarily involved subcortical pathways. Under this circumstance the cleavage between the normal and curare states did not occur: normal learning appeared in the curare-state, and conditioning developed in the drugged animal appeared after recovery (**8**).

During the past few years there has developed an increased interest in the use of curare and allied drugs in the treatment of tetanus (**18**), spastic paralysis (**2, 19**) and the reduction of the convulsions in metrazol-shock treatment of psychotics (**1, 16, 17**). Due to the traditional unreliability of curare, substitutes have been sought. Attempts have been made to procure a more purified form of this drug (**7**), and even to prepare a 'synthetic curare' (**1**). Folkers and his co-workers (**5, 6**) have prepared crystallized erythroidine from the seed Erythrina, and it has already been tested clinically in two forms, beta erythroidine hydrochloride (**2, 16**) and dihydro beta erythroidine hydrobromide (**19**). The action of erythroidine is said to be due to a quaternary ammonium base, which property it apparently has in common with curare.

Our first concern has been to determine whether the dissociative effect produced with curare could be duplicated with erythroidine. As suggested earlier (**8**, p. 399f), this would enhance the experimental approach to these problems by the substitution of a more reliable laboratory prepared chemical in place of curare. The study has also been directed to a preliminary determination of the demarcation between the dissociative and normal states, and an analysis of the behavior of the total organism in the drug-state in contrast to the isolated muscle CR hitherto reported.

Procedure

The drug, curare or dihydro beta erythroidine hydrobromide, was made up in a distilled water solution and, unless otherwise indicated, injected intravenously. Artificial respiration was maintained by means of a Harvard respirator and a catheter inserted into the trachea by mouth within a few seconds after the drug took effect.[3]

[3] In this connection, the caution previously cited (**11**, p. 264) must be rigorously followed: fatality of the animal may easily follow premature withdrawal of the catheter upon the return of voluntary breathing. Due to flaccidity of throat musculature and excessive secretion of saliva at this stage of the recovery process, death will occur from suffocation. Maintaining

In the present study, unlike the technic previously employed (11), the semitendinous muscle, excepting one or two test cases, was not exposed; the *intact* animal was used. The age of the eleven dogs ranged from seven weeks to six months.

While the dosage with erythroidine is more dependable than with curare, it is apparently not related to body weight as such. Once the proper dose had been established for a particular animal, one could expect similar results with subsequent sessions. If repeated sessions were taken very rapidly however (3 to 4 experimental periods within a couple of days), the same size dose was more effective in later sessions. There is no increase in tolerance, nor risk of fatality with repeated sessions. As many as five successive drug sessions with curare or erythroidine or both have been given within a 24-hour period with impunity. With proper precautions and use of small doses at the start, fatalities will be rare if not completely eliminated. In a rare case death will result from sudden cardiovascular collapse due to some undetermined idiosyncrasy. When intravenous injections are not practical, the drug can be given orally.[4]

The conditioning situation in the drug-state was basically simple.[5] The conditional stimulus (CS), bell (B) or a spot-light (L), was presented from 2 to 4 seconds and terminated with the simultaneous presentation of shock (US) to paw of *hind* leg. In some cases, in order to study the relative efficacy of L and B as well as observe the pupillary changes, L was presented for four seconds

artificial respiration *until the animal can stand and walk* will reduce the hazards of fatality to a minimum. As will be shown in this paper, *the return of voluntary breathing is no sign that the animal has returned to normal.* When necessary, prostigmin (1 : 2000) is usually effective in bringing the animal around in a few minutes. A considerable drop in blood pressure results from the injection of prostigmin and the animal may die from a massive dose of the drug. We have found that the best results are procured with the injection of 1 cc. at a time and, when necessary, spacing supplementary doses at not less than five minute intervals. Human doses have been somewhat larger than those we have employed with the animals.

[4] Unlike curare, which must be introduced directly into the blood stream, erythroidine is equally effective by oral administration (19). From our own observations this technic is feasible and, with some animals such as cats, probably has its advantages. None the less, we have for the most part adhered to intravenous injections. By this method the total dose is effective at once, and it is thus possible to make more accurate determinations of dosage, duration of drug-state, recovery sequence, etc. These processes are more difficult to follow when the drug is introduced orally, particularly with mild doses, since the action is delayed some 10 to 20 minutes. In any case, erythroidine requires more care in handling since it is effective orally. In passing, we have found that the present form, dihydro-hydrobromide, is much more potent than the earlier derivative, beta-hydrochloride.

[5] One should not assume that, since the animals are drugged, liberties can be taken with the usual controls necessary in conditioning. All artifacts must be eliminated. It has been observed, for instance, that animals in the mild drug-state readily react and condition to such noises as relay-clicks, action of the experimenter, etc. During the preparation of a 16 mm motion picture film, it was necessary to use a second empty camera or else adapt the animal to the camera-noise before auditory stimuli could be used. Otherwise, the camera-noise soon served as a conditional stimulus. This particular difficulty was also obviated by the use of visual stimuli.

during the last two seconds of which B was sounded (L + B); both were then terminated with the simultaneous presentation of US. The shock was accompanied by a characteristic buzz-noise which has proven useful in other conditioning studies (**3**). One could thus omit US when the desired response was obtained and still have some effective reinforcement because of the shock-buzz.

Some of the animals were conditioned in the normal state, either before or alternated with drug-state tests. They were placed in the conventional stock (*cf.* **3**) and the CS, T, was followed by momentary shock to right forepaw. In brief, *drug-state* training involved L or B or both with shock to *hind* paw, whereas *normal* conditioning made use of T with shock to *fore* paw. *Tests with CS were regularly made before and after each drug-session. Since they were uniformly negative they have been largely omitted from the tabular results below.*

Results

No. 1.—This naive animal was subjected to preliminary tests with erythroidine introduced orally, at 5:22 P.M. on May 28th. Conditioning to L + B proceded as follows: 0/6, 6/10, 4/10 and 7/8. Shock reinforcement was applied on 28 trials, and the CR consisted of a diffuse body reaction including responses of the tail, hind legs, and twitches of the ST muscle (which were detected manually). The animal was never very deeply under the drug, and required artificial respiration only after the 11th trial at 5:51 P.M. Before training, the UR to L consisted of a rapid constriction of the pupil (P) to a 'pinpoint,' followed by some dilation upon the sounding of B. The body remained completely inert. After conditioning, diffuse, somatic responses were evoked by these stimuli, as noted above, and the pupil tended to dilate considerably to the CS.

According to the protocols the CR was noted to develop primarily to B, and to a lesser extent to L. Tests at 6:14 P.M. with separate presentations of B and L confirmed this observation, the score to B being 4/4 and to L 2/4. This is in confirmation of our experience in conditioning normal animals for localised paw-flexion responses: training with L requires many more trials than to B. It is perhaps not irrelevant that normal human reaction time is quicker to sound on the average by about 50 miliseconds.

TABLE 1 *

No. 2

Time	Drug Session	CS	US	CR Scores
3:52	II			
4:03–4:16		L+B	11	11/12
5:06	III			
5:10		L+B		0/3
5:11–5:46		L+B	23	21/25
1:46	IV			
1:52		B		2/2 (?)
1:53–2:06		B	8	0/2, 8/8
2:56	V			
3:02		B		2/2

* *Interpretation.*—The successive erythroidine drug-sessions are indicated by the roman numerals. The digits in the 'US' column give the total number of shock-trials. Under 'CR Scores' the numerators of the fractions denote the number of CRs and the denominators give the total number of trials. When no digit appears in the US column, CS was presented alone. Score followed by '(?)' indicates a questionable response. Tests with CS were made before and after each drug-session: *they were all completely negative* (*cf.* text).

No. 2.—After a preliminary test of the drug, training of this animal was begun in the second session with erythroidine on May 29th. As summarized in Table 1, conditioning to L + B was effected very rapidly. The response again consisted of a generalized reaction involving the entire body in one concatenation or another: limbs, tail, ST and even lifting of the head. Again it was noted that conditioning was effected first to B rather than L. The training in the 2nd and 3rd sessions was completed before voluntary breathing returned. Evidence of carry-over did not appear until the final tests on May 31st in the fourth and fifth sessions. The results in the last period were completely unequivocal. In all, a total of 42 shock-reinforcement trials were given in the three sessions prior to the carry-over into the 5th session. All tests made in the intervening normal periods were completely negative: the CS invariably failed to evoke any sign of the CR. Here we see that the diffuse-CR in the drug-state was dissociated from the behavior of the normal animal, since the CR never appeared in the normal, but carried over spontaneously from drug-state to drug-state. This evidence, for the first time, offered proof of the similarity in action of erythroidine with that previously reported with curare for the isolated ST muscle.

No. 3.—This animal was first subjected to normal fore-paw conditioning. The scores of the four tests from May 23rd to June 1st are as follows: 1/25, 3/25, 13/25 and 3/25. As with the previous animals, conditioning in the drug-state developed first to B and then to L. As summarized in Table 2, the CR was evoked by B after 15 trials, and did not appear with L until after 20 trials (1st drug-session). The discrepancy in the total number of trials (24 for B and 36 for L) is due to continued training with L-alone after CR to B had reached 100 percent. The form of the CR was again diffuse, involving the entire body in a generalized reaction. The

TABLE 2*

No. 3

Date	Time	Drug Session	CS	US	CR Scores
June 3	3:15–4:19	I	L + B	20	0/20, 13/16
				16	0/10, 3/5, 9/9
	7:55	II			
	8:01		L+B		1/1, 0/1
	8:04–8:19		L	9	0/6, 4/4, 9/10
	8:31–8:32		L		2/2
June 4	10:17	III			
	10:23		L		2/2
	10:25–10:34		L	9	25/29
	10:59		L		1/1
June 8	10:45	IV	L+B		5/5
	10:52–10:56		B, T		0/2, 0/2
	10:58		L		3/3
	11:00–11:12		L	9	0/1, 11/11
	12:02	N	L		0/3
June 13	2:37	V			
	2:40		L		0/1, 3/3
	2:43		B		4/4, 0/6
	2:46–3:03		L	11	26/28
	2:51–3:02		B		5/12
	3:14		T		0/3
	3:15		B		0/3
	3:16–3:19		L	1	4/4
	3:41	VI-C			
	3:47			1	DMR
	4:06, 4:15		L		3/3, 3/3

* *Interpretation.*—When 'C' appears under 'Drug-Session,' animal was subjected to curare; otherwise erythroidine was used. 'N' indicates test in the normal state after animal was again able to walk. When 'Time' or stimuli ('CS' – 'US') are separated by a comma, the results are to be considered separately. Thus in the 4th Session, from 10:52 A.M. to 10:56 A.M., B and T were presented separately and each time each stimulus scored 0/2 (no) CR. Also *cf.* Table 1.

carry-over to the 2nd session was definite, although the magnitude of the response was not very great and evoked only by B.

After more training, L — CR now carried over into the 3rd session and, with still more reinforcement, was maintained for a period of four days into the 4th session. As was to be expected, B and T now evoked no responses. Activation of the apparatus at this time in the usual way, except that L was omitted, also failed to evoke a response. This check indicated that the CR was actually to L and not to some secondary auditory cues that might have been produced by the apparatus. After further reinforcement L — CR carried over for a period of five days into the 5th session. Some spontaneous recovery of B — CR now appeared. This cannot be considered an artifact since no responses were evoked by T at this time.

Further reinforcement was given to L — CR (making a total of but 39 shock trials from the 2nd-to-5th sessions) and it now carried over into the 6th session, this time induced with curare. The latter drug was somewhat more potent. Six minutes after injection, US evoked only DMR (*cf.* footnote 1). Even after the recovery of some muscular function, the striate reactions were much more attenuated than they had been in the erythroidine drug-state. The animal was, however, capable of some diffuse behavior and unequivocal CRs were evoked in this session. The CR was manifested in the form of tail movements, skin twitches, widespread muscle 'ripples' and shivering movements of the entire body. On some of the last trials the CR pattern involved mild struggle reactions. These tests were well spaced in two groups of three, some 9 minutes apart. L presentations were carefully restricted to intervals of quiescence. On every one of the six trials, a CR was evoked.

No. 4.—Fore-paw flexion CR to T was first developed in the normal state from May 24 through June 7th in six sessions, the results of which were: 1/30, 16/25, 15/25, 23/25, 20/25, and 24/25. As indicated in Table 3, carry-over of the drug-state CR occurred in the 2nd session

TABLE 3 *

No. 4

Date	Time	Drug Session	CS	US	CR Scores
June 6	11:26	I			
	11:33–11:43		L	8	2/5, 7/11
	11:48–11:52½		L		5/5
June 8	12:23	II			
	12:25		L		1/2
	12:26–12:27		L	2	5/6
	12:55–12:58		L, (B)		3/3 (0/2)
June 14	10:33	III			
	10:38		L		2/2
	10:43–10:50		L	3	9/10
	11:19	IV-C			
	11:24–11:47		L		4/6
	12:35–12:58		L		8/8

* For interpretation, *cf.* Tables 1–2.

and unquestionable evidence was procured in the 3rd session. The general form of the CR was as previously recorded: specific or generalized twitches varying in magnitude as a function of the depth of the drug-state. In all intervening normal periods the conditioning was completely repressed, nor did the normal CR to T ever appear in the drug-state. Carry-over of the drug-state CR from erythroidine to curare was successfully attained in the 4th session.

Prior to this animal, the drug-state CR was always noted before the return of voluntary breathing. In this case it was evident after this function returned. A number of tests, not recorded in Table 3, were made in the 3rd session as a preliminary determination of the upper limit of the drug-state. The drug-state CR persisted undisturbed following the return of voluntary breathing, elimination of artificial respiration, and the removal of the tracheal catheter at 10:51 A.M. Positive CR to L was evoked as late as 11:01 A.M. Interpolated tests with B (0/2) and T (0/9) were completely negative, indicating that the CR was specific to L. The drug-state therefore was not a function of the kinesthetic-proprioceptive pattern produced by tactile stimu-

lation from the catheter or the air-stream in trachea coming from the respirator. This test was made on a number of occasions in different animals all with the same results.

No. 5.—From May 24th until June 8th six training sessions in the normal state with T were made with the following results: 8/25 10/30, 14/25, 19/25, 24/25 and 25/25. Drug-state training was initiated on June 10th under erythroidine and progressed very rapidly. With but 10 shock-reinforcement trials, the CR was maintained for a period of ten days when it reappeared spontaneously in the 3rd session on June 18th. (An intervening session on June 15th had no bearing on this fact since a positive response to L was evoked in this brief session and no shock trials were given.)

In the 3rd session CR to L was extinguished in 27 trials and reconditioned with 7 shock-trials. The results are summarized in Table 4. It was again noted that the drug-state CR

TABLE 4 *

No. 5

Time	Drug Session	CS	US	CR Scores
1:50	I			
2:08–2:20		L	10	0/10, 9/10
2:21		L		1/1
1:48	III			
1:58		L		2/2
2:02–2:09		L		9/10, 4/5, 0/10
2:10–2:15		L	7	0/1, 11/11
2:20		L		1/1
2:22		B		0/2
2:28		L		1/1
2:38	N (?)	L		2/2 (?)
2:44	N (Walks)	L		0/2
3:07	IV-C			
3:12–3:25		L		6/10, 7/10, 2/5, 0/14
3:52	V			
3:56				0/4
3:59		L	10	0/1, 11/11
4:06		L		6/6

* *Interpretation.*—'N (?)' indicates uncertainty as to whether this represents normal or drug state. Also *cf.* Tables 1–3 and text.

was uninterrupted with the return of voluntary breathing at 2:27 P.M., and was repressed only when the animal was once again able to walk. The reactions at 2:38 P.M., when the animal was just barely able to stand, are equivocal and hard to interpret. According to the actual protocols, upon two successive presentations of L, the animal 'gets up from a resting crouch position and turns away' or 'haunches back.' Clearly we have a condition approximating the borderline between the normal and the drug-state, but it is difficult to say on which side of the dividing line the animal was at this time.

We again find that curare and erythroidine were equivalent, since the CR carried over spontaneously from the 3rd erythroidine to the 4th curare session. After extinction in this period, the CR was also absent in the following erythroidine session. Reconditioning proceeded very rapidly.

No. 6.—Additional checks on the authenticity of the drug-state CR were made with this animal. On June 20th in the first drug-session, from 11:15 A.M. to 1:00 P.M., a series of trials of T and L were given without shock. Except for the usual pupillary constriction to L and slight dilation to T, no responses were evoked by these stimuli at any time; the entire body remained inert from beginning to end. In the second drug-state session (same day) a series of 48 US trials (shock-alone to hind paw) were given from 1:12 P.M. until 2:40 P.M. The responses were the usual unconditioned reaction of the striate musculature, varying in extent and magnitude as a function of the depth of the drug-state. Interposed were some 15 trials of L-alone and 8 trials of T-alone. At no time, did the T or L ever evoke a striate reaction. This served as

check upon pseudo-conditioning, for we see that the drug-state CR was not simply due to heightened level of responsiveness, but the result of actual pairing of stimuli.

The results of the 3rd to 9th sessions, inclusive, are tabulated in Table 5. Many of the trials in the 3rd and 4th sessions (same day) were undoubtedly wasted, due to the cumulative

TABLE 5 *

No. 6

Time	Drug Session	CS	US	CR Scores
2:44	III			
2:51–3:44		L	94	0/50, 3/10, 7/20, 10/20, 11/20, 4/7
4:15	IV			
4:18–5:19		L	80	13/50, 19/50, 23/28
5:43	V-C			
5:50–7:04		L		0/8
1:30	VI			
1:32		L		0/2
1:33–1:51		L	21	0/5, 8/10, 2/10, 7/10
1:53–2:01	N (?)	L		0/3, 0/3
2:04	VII			
2:25–2:32		L		7/8
2:54	VIII-C			
2:58–3:07		L		0/3
3:11–3:19		L		5/5
3:40–3:56	Ether	L		0/11
4:15	IX			
4:20		L		0/1
4:20½			1	DMR
4:49		L		4/4

* For interpretation, *cf.* Tables 1–3. Number under 'US' without accompanying symbol in 'CS' column indicates the number of shock-trials alone. Thus in the 9th session at 4:20½ P.M., shock was applied once, producing only direct-muscle-response (DMR).

effect of the drug, resulting from so many administrations in close succession. Voluntary breathing did not reappear in the 3rd session until 4:09 P.M., about 25 minutes after the completion of the training series. Four days later on June 24, training was continued in the 6th and 7th sessions under erythroidine, and we find some carry-over into the following (8th) curare session. Tests under light ether anesthesia were entirely negative, and the CR reappeared in the 9th final erythroidine session at 4:49 P.M. Failure at 4:20 P.M. (0/1) was due to the extreme depth of the drug-state. Test with shock-alone right afterwards was noted to produce only DMR, the animal being 'inert and too deep' (from protocols). When the animal was again capable of responding, we find at 4:49 P.M. a perfect score: 4/4. In all cases, of course, drug-CR was completely depressed in the intervening normal states.

No. 7.—This naive animal was trained in the erythroidine drug-state and tested under curare. The results are summarized in Table 6. As with the previous animal, shock alone in the first session failed to result in a pseudo CR when L was presented alone. As in *No. 6* a number of the training trials were given when the animal was too deeply under the effect of the drug. Thus in the 2nd session many of the first 30 trials could just as well have been omitted. Shock at this time (not indicated in the table) only produced DMR, indicating a complete block at the motor-end-plate. When the animal was capable of striate responses, the CR developed readily. The CR on the last trials in this session (score 7/10) consisted of strong generalized reactions. Failure of the CR to appear in the 3rd session (omitted from the table) indicated the necessity of more training, which was accordingly given in the 4th and 6th erythroidine sessions. The carry-over in the alternate curare sessions, 5th and 7th, was not too definite. Following more training in the 8th, erythroidine, session the CR finally carried over unequivocally to the final (9th) curare sessions. The form of the CR consisted largely of twitches of the right hind leg.

TABLE 6*

No. 7

Date	Time	Drug Session	CS	US	CR Scores
June 25	2:10	I			
	2:11–2:27			7	Diff. UR
	2:20		L		0/2
	2:44	II			
	3:11–3:30		L	37	0/10, 2/10, 4/10, 6/10, 7/10
June 26	1:36	IV			
	1:41–2:17		L	25	4/17, 7/12, 7/8, 13/19
	2:53	V-C			
	2:56–3:16		L		1/2, 0/7, 2/2
June 27	1:56	VI			
	2:00		L		2/2
	2:02–2:10		L	4	8/9
	2:13, 2:22		L		3/3, 4/6
	3:56	VII-C			
	4:00, 4:10		L		0/8
	4:11			3	DMR
	4:25		L		2/2 (?)
June 28	1:00	VIII			
	1:04		L		0/1
	1:05–1:45		L	48	18/25, 11/25, 0/10, 14/15
	1:46		L		1/1
	1:47	N (?)	L		0/1
	1:49		B		0/1
	1:50–1:53		B	6	0/1, 5/6
	2:09	N	L		0/2
			B		2/2 (?)
	2:13	IX-C			
	2:25–2:32		L		7/13
	2:31–2:35		B		1/4 (?)
	2:37		L		2/2

* For interpretation, *cf.* Tables 1–3, 5 and text.

In general the nature of the CR was a function of the possible responses, which in turn depended upon the depth of the drug-state. The deeper the drug-state, the weaker and more restricted the responses; the lighter the effect, the more generalized and stronger the responses. Thus in the 8th session the responses at first (18/25) consisted of weak 'shrugs.' At the end (14/15), they all consisted of continuous struggle reactions of the entire organism initiated with onset of L and often continuing after cessation of stimulus.[6] As reported for *No. 4*, the drug-state was not an artifact resulting from artificial respiration. After the satisfactory return of voluntary breathing, the tracheal catheter was removed and the respirator halted at 1:45 P.M. in the 8th session. Yet L still evoked a strong CR a minute later. This test was apparently made quite close to the border between drug and normal states, for at 1:47 P.M. L failed to evoke CR, during which time "the animal was making unsuccessful attempts to stand" (from the protocols). As indicated in Table 6, a CR was quickly established to B at this time.

Here we have the first attempt to establish a CR near the borderline between the two states. On return to complete normality at 2:09 P.M., L as usual is negative, but on two trials of B, animal 'crouches, turns and walks away' (from protocols). What this represents is at this time hard to say. Since we have never found the drug-state CR to carry over to the normal period in animals properly trained under the drug and possessing intact brains, it would seem that

[6] The score of 0/10 in the middle of this session was due to premature withdrawal of catheter and artificial respiration at the first sign of voluntary breathing. With this the animal started to expire and respirator had to be started at once. Within a short period of time we get the final score 14/15.

the animal was normal from 1:50 to 1:53 P.M. during which interval B — CR was established. This is supported by the fact that the L — CR was repressed only to reappear in the following, 9th, session. However, it is not certain whether the responses at 2:09 P.M. are true CRs or the unconditioned reactions of naive animals to loud startling stimuli, such as buzzers. The difficulty of interpretation is increased by the reaction in the 9th session to B (1/4?), which was extremely doubtful. Due to the unconditioned properties possessed by buzzers, it would seem highly advisable, in future work, to restrict the CS to L. In any case, drug-state CR to L carried over without question from the 8th, erythroidine, session into the 9th, curare, period, remaining suppressed in the intervening normal period.

No. 8.—This naive animal was subjected to four drug-sessions, the first two on June 8th and the last two 24 hours later. In this case the usual procedure was now reversed: the animal was first trained under curare and then tested under erythroidine. As indicated in Table 7,

TABLE 7 *

No. 8

Time	Drug Session	CS	US	CR Scores
12:42	I-C			
12:50–1:14		L	44	2/30, 6/15, 5/11
1:41	II-C			
1:43–1:59		L	32	3/10 (?), 2/10, 0/15
2:04–2:39		L	35	3/10 (?), 10/20, 10/20, 4/5
2:41–2:42		L		3/3
2:48	N	L		0/1
12:24	III-C			
12:28–12:51		L	16	3/10, 6/10, 5/5, 6/6
1:17	IV			
1:46			1	Diff. UR
1:49–1:53		L		4/4
1:52		B		0/4

* For interpretation, *cf.* Tables 1–3, 5.

the CR carried over to erythroidine after three sessions of training under curare. Again, a number of trials were undoubtedly wasted, during intervals in which the animal was too depressed for the training to be effective. The training in the 1st session was completed before the return of voluntary breathing at 1:14 P.M. In the 2nd session, artificial respiration was discontinued at 2:40 P.M. upon the satisfactory return of voluntary breathing and it is noted that the CR was still present from 2:41 P.M. to 2:42 P.M. Once the animal could stand at 2:48 P.M. the CR, however, was repressed.

The results in the 3rd, curare, session agree with those of the previous animals under erythroidine: the form and intensity of the CR was a function of the muscular responses possible at the time. Thus at first (3/10 and 6/10) the CR consisted of light 'shiver' reactions, like 'ripples' or waves. Later (5/5) the CRs were more intense, and best described as 'shrugs.' Finally, in the lightest state (6/6) the CR consisted of a violent struggle of the entire body, limbs, head and neck. In the 4th session, under erythroidine, the CR was evoked with further application of CS on each of four well spaced L-trials. An equal number of interposed B-trials were all negative, as would be expected since CR to B had not been established. The L — CR was a continuous struggle reaction of the entire organism.

Upon return to normal after the 4th session, at which time CR was as usual repressed, the semitendinosus muscle of the right hind leg was exposed under ether anesthesia. After recovery from the ether the animal was then subjected to three more sessions with erythroidine on June 9th (not included in Table 7). In these tests an attempt was made to develop a specific CR of the semitendinosus muscle. Unlike our previous results (**8, 11**), the animal was now capable of widespread reactions. As could be expected the CR tended to be generalized, as is the case with the initial reactions of normal animals in the stock conditioning situation. In the latter, the localized forepaw flexion CR develops only after at least a hundred trials. In the present case, with erythroidine, the following procedure was followed: shock was applied if

CR was diffuse without ST component, and omitted if CR pattern involved the ST response. At first, the CR was diffuse, as noted in sessions 1–4 (Table 7). After a total of about 195 trials, of which 110 were with shock reinforcement, a specific ST − CR without a diffuse component developed to B (score 4/4 on final test), whereas CR with L still contained some diffuse components (final score: 3/4).

No. 9.—This naive animal, like the previous one, was first trained under curare and then tested with erythroidine. All four sessions were given on June 10th, and the results are summarized in Table 8. As with erythroidine, the form of the CR in the curare-training-sessions

TABLE 8 *

No. 9

Time	Drug Session	CS	US	CR Scores
12:54	I-C			
12:59–1:15		L	20	2/10, 3/10, 2/5, 5/5, 3/4
1:49	II-C			
2:14–2:29		L		0/6
2:53	III-C			
2:55–3:15		L	28	0/10, 4/10, 6/10, 9/10, 8/11
3:30–3:35		L		2/2
3:51	IV			
3:53			1	DMR
4:16		L		2/2

* For interpretation, *cf.* Tables 1–3, 5.

changed from weak 'ripples' to violent struggle reactions as the animal progressed from the deep to light drug-state. In the 4th, final, session shock-alone at 3:53 P.M. evoked only DMR, indicating an inert animal. Even spasmodic breathing reflexes could not be detected at this time. When some muscular activity was possible at 4:16 P.M., L produced clearcut unequivocal CRs. The first CR was a continuous 'shiver' reaction lasting the final two seconds of L. The second CR consisted of a violent continuous struggle for the entire four seconds of CS. Conditioning under curare was thus manifested under erythroidine. From these data, and those of the previous animals, it is clear that the drug-state is the same, whether it be induced with curare or erythroidine.

No. 10.—This naive animal was tested on June 15th in the same fashion as *No. 8* (sessions 4–7). The semitendinosus muscle was first exposed under ether, and after recovery from the anesthesia the animal was subjected to erythroidine at 12:59 P.M. Training to L was continued from 1:04 to 1:32 P.M., with the following results: 0/15, 3/10, 4/5, 1/5, 2/10, 7/10, 4/10, and 4/5. The initial CR appeared on the 17th trial and consisted of a generalized reaction. The first contraction of ST appeared on the 25th trial, and the form of the CR thereafter consisted of ST or diffuse reactions or both. The fall in CR scores after attaining a level of 4/5 (by the 30th trial) was due to the fact that shock reinforcement was applied if CR was diffuse and omitted only if CR was limited to ST. Voluntary breathing returned about one minute after the completion of the tests, at 1:33 P.M., and complete recovery set in by 3:00 P.M. The failure of the CR to be restricted completely to the contraction of the ST in this case is clearly due to insufficient training (contrast with *No. 8* above).

No. 11.—This animal was tested under erythroidine on June 15th. A very small dose of the drug was injected at 2:35 P.M. in an attempt to procure the lightest possible drug-state. The training, from 2:40 P.M. to 2:50 P.M., progressed very rapidly as the following scores attest: 0/5, 5/10, 12/13. The form of the CR was the generalized struggle found in the light-state. Shock reinforcement was applied on sixteen trials. Voluntary breathing returned at 2:45 P.M., after the 14th CR trial, and the catheter was removed and artificial respiration halted. Within one minute after the tests were completed, at 2:51 P.M., the animal was just barely able to maintain an erect position if so placed. The drug-state is clearly maintained until the standing stage is approximated. Whether it persists after this point in the recovery cycle is still to be determined.

Tests with light after complete recovery were negative indicating that the training was limited to the drug-state.

Discussion

From the results of this study it seems clearly established that learning developed in the drug-state, whether with curare or erythroidine, is truly *dissociated* from the behavior of the normal animal. It is noteworthy that the animals submit to successive intravenous injections of the drug without complaint or protest. In no case did any animal, properly trained in the drug-state (before complete recovery set in), ever 'condition' against the test-table, hypodermic syringe, experimenter or any other element of the experimental configuration. Contrast these results with those procured in conditioning normal dogs with morphine injections. After several trials the dogs began to salivate at the sight of the experimenter opening the box containing the hypodermic syringe (**14**), became nauseated and vomited when placed in the test-stock (**13**). No sign of such defense conditioning ever developed in the drug-state experiments reported with curare or erythroidine. Our clinical observations bear out the more strictly experimental data: the drug 'experiences' are amnesic.

In the previous studies (**4**, **8**, **11**) every attempt was made to reduce the behavior in the drug state to the irreducible minimum: *i.e.*, response of the isolated semitendinosus muscle. When other muscles were once again able to contract training was halted. This was done to avoid any criticism that the curare-conditioning was perhaps, after all, learning in the normal state. This criticism, of course, is entirely specious, since the curare-CR was always repressed upon recovery from the drug. Due to the large doses used, all overt (striate) action other than the contraction of ST was depressed. Voluntary breathing was as a consequence also eliminated, necessitating artificial respiration as a regular practice. In the clinical therapeutic studies (**1**, **2**, **16**, **18**, **19**) only by accident were the doses large enough to interfere with respiration, and prompt action was taken at once to counteract this lapse.

In the present study the conditioning process and the analysis of the nature of the CR were tested in the intact animal. For the first time, the experimental conditions in some cases approximated the mild effects procured in clinical therapeutic studies. In most cases, tests of conditioning were made after the return of voluntary breathing, and even sometimes after the recovery of some degree of limb tonus. From the present data it becomes clear that the form of the drug-state CR is a function of the possible responses. When the animal is in the very deep state, no overt response other than the direct contraction of muscle to shock (DMR) occurs. At this point,

of course, striate CR cannot be evoked at all.[7] In a lighter state, twitches of the skin, tail, paws or stomach muscle are detected. These responses (UR) are produced by shock before conditioning and, after training, appear as CR. In the very light drug-state, more generalized diffuse action is possible, and these responses form the CR pattern. Whether the response pattern, UR or CR, is to be restricted and weak, or diffuse and intense, is simply a function of the peripheral status—whether the block at the motor-end-plate is great or small. The reduction in block at the myoneural junction in no way disrupts or interferes with the drug-state, but simply determines the form the striate UR or CR is to take. In other words, the form of the CR developed from a specific, isolated muscle-response to the widest gross body-pattern from deep to mild drug-states. Whether the drug be curare or erythroidine is unimportant, since the behavioral dissociative action of the two drugs is shown here to be identical.

What constitutes the demarcation between the normal and dissociated drug-state? One indicator is, of course, the drug-state CR. Thus, as the effects of the drug disappear there is an increasing return of functional use, from the first spasmodic breathing twitchings until the animal stands and walks; the animal regains one function after another. The exact order is yet to be determined.[8] But *on return to normality there is loss of one function: the conditioning established in the drug-state.* The failure to respond to CS is as true a sign of normality as the ability to stand and walk, although the latter two abilities are obviously more easily tested.

The other valid criterion of normality is the ability *to stand and walk.* Once this stage had been attained, the drug-state CR was never evoked. It seems probable that the reappearance of the normal state is not due to the obvious reduction of the peripheral paralysis, but to the elimination of the cortical depression. We have noticed, on a number of occasions, that even after muscle tonus had

[7] This does not mean that the organism is completely inert, nor that the associative processes are completely inhibited. While we have never procured striate CR with training limited to the very deep drug-state, in which DMR is the only overt reaction to shock, there are blood pressure changes evoked which are capable of being conditioned (*cf.* **9**).

[8] Recovery in the last few minutes in the drug-state proceeds very rapidly. Precise study of this problem, particularly at the borderline, will be possible only by continuous drip-intravenous-injection which will maintain the animal at a given level of the drug-state. By the present method we are forced to observe a constantly changing animal and can complete the behavioral picture only by repeated drug sessions, and at that with some details missing.

Tests with CS in the borderline condition are thus handicapped. The CR to B in *No. 7* in the 8th session (Table 6) was clearly on the borderline between the two states, but, because of the changing animal, is hard to interpret. Similar results have been reported in cats by Harlow (**12**). A CR was established to B in 11 trials, in what is called 'Stage II,' in which diffuse responses are evoked by shock and animal has 'difficulty in maintaining posture.' The CR in this case was maintained after complete recovery. Harlow's stage II is perhaps even nearer to normal than the present borderline data, in which the animal cannot as yet stand.

reappeared placing movements were still absent. Through the work of Bard we know that this function is dependent upon the somesthetic sensory cortex. The animals in the last stages of the drug-state, before returning to normal, are therefore apparently in a condition similar to that found in locomotor ataxia, in which the difficulties are not in the motor apparatus, but due to a sensory impairment. In the present case, the proprioceptive mechanism is disturbed, not because of injury to the sensory pathways in the spinal cord as in tabes dorsalis, but as a result of cortical inhibition of the proprioceptive mechanism. There is, of course, also in the drug-state a depression of the motor cortex, but the above analysis rests upon the fact that muscle tonus returns before walking develops.

It is perhaps futile to raise the question of the experiencing organism in the absence of appropriate introspective evidence. This is doubly hazardous when analyzing animal data, and all interpretations are suggested most tentatively. To the extent that inferences are permitted from the action of the autonomic nervous system and the generalized overt behavior, certain conclusions seem indicated. During conditioning in the mild-drug-state, heart acceleration is produced by galvanic stimulation, respiratory changes are effected, and extreme pupillary dilation occurs. As the training becomes effective these responses are also evoked by CS, light or bell.

These responses are autonomic in origin (**9**, **10**). In the mild drug-state, generalized 'struggle' behavior becomes part of the conditioned pattern of response. This phenomenon is strikingly similar to that demonstrated in the total decorticate preparation, or the excited behavior of the normal animal in 'rage' or 'anger.' These widespread emotional conditioned responses are repressed after recovery. As tested by the same criterion applied in our previous studies, this repression cannot be attributed to extinction, since the CR reappears *spontaneously* when the drug-state is reinstated.

Since the drug-state CR previously reported consisted of the response of the isolated muscle, there was some hesitancy in accepting the description of 'dual personality' applied to the original findings (*cf.* 4). Because there was no evidence concerning concomitant emotional components, the writer had suggested as a substitute concept a term which seemed at the time more appropriate: *amnesia* (**8**, p. 405). The diffuse conditional reactions involving concomitant autonomic ('emotional') disturbances in the drug-state reported in the present study, however, do seem to give real basis for the use of the term 'multiple personality.' The contrast in behavior between the generalized rage in the light drug-state after conditioning and the indifference to CS, light or bell, after recovery is extreme.

The naive observer of the generalized struggle-CR in the very mild drug-state would find it extremely difficult to differentiate this

behavior from that of normal 'rage.' The confusion would be even greater if the observations were made when the animal had recovered sufficiently to permit removal of catheter and thus eliminate artificial respiration. During this interval, even the experimenter might be at a loss, and would be able to ascertain the true situation only by determining the reaction to CS, and whether or not the animal could stand or walk. Written description is almost inadequate and, in this case, to see is to believe.[9] Here we are faced with dissimilar reaction-patterns to the same stimulus, such as characterize the dissociations which occur in 'split' personality.

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[9] Pictorial representation is far superior to any written description, and accordingly a 16 mm motion picture film, "*The psychodynamics of dissociated behavior in the drug-state*," is now in preparation.

For purposes of comparison, the drug-state CR of ST has been recorded in a separate film, "*The dissociative effects of curare*," The Psychological Cinema Register, Bethlehem, Pa., 1940.

RETENTION AND SUBSEQUENT EXTINCTION OF A SIMPLE RUNNING RESPONSE FOLLOWING VARYING CONDITIONS OF REINFORCEMENT *

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Introduction

In a previous paper (1) the writer described the effect of various conditions of reinforcement upon the acquisition and extinction of a simple running response in the rat. It was demonstrated that although the condition of 16 reinforced acquisition trials led to the most prompt response at the end of the acquisition series, the condition of 8 reinforcements distributed randomly among the 16 trials was followed by a less rapid initial extinction rate and was characterized by significantly greater resistance to final extinction (as measured by the number of extinction trials required to reach a non-response criterion). The writer did not attempt to explain this difference on the basis of an hypothesis of 'expectancy,' [1] for it was further discovered that even the condition of 8 consecutive reinforced acquisition trials was followed by greater resistance to extinction than was the condition of 16 reinforcements (difference significant at the 8 percent level). In other words, the greater amount of reinforcement yielded the faster response at the end of acquisition, but led to the more rapid extinction after reinforcement was withdrawn. To account for this apparent contradiction of traditional learning concepts several possible explanations were presented for experimental testing.

One of the suggested explanations is tested in the study reported here. The original postulation was to the effect that each reinforced response might involve not only a positive effect, such as 'excitation,' but also a negative effect, such as 'inhibition.' The sum of these negative increments at the end of acquisition would then be greater for the animals having had 16 reinforced trials than for those having had 8 reinforcements. It was further supposed that this inhibitory process would not greatly affect final acquisition level, but that the inhibitory increment produced by any extinction trial would be pro-

* This experiment was conducted in the Psychological Laboratory of Brown University.

[1] For Humphreys' postulation of the 'expectancy' hypothesis see 6 and 7.

portional to the amount of inhibition already accumulated. It would then follow that the condition of 16 reinforcements, while leading to most prompt response at the end of acquisition, would be followed during the extinction series by a more rapid building up of inhibition than would the condition of 8 reinforcements, and would therefore lead to relatively early extinction. The facts of spontaneous recovery suggest that with the passage of time the inhibition is dissipated more rapidly than is the excitation, and that the excitatory residue thus becomes relatively more potent in determining the response. It was therefore predicted that if an interval of 24 hours were allowed to elapse between the last acquisition trial and the beginning of the extinction series, the 16-reinforcement animals would resist extinction more than would the 8-reinforcement rats, due to the higher level of excitation built up during the 16 trials of acquisition and still remaining in the system.

In view of these considerations the conditions of the present experiment were made to differ from those of the earlier study by the interpolation of a 24-hour interval between the acquisition and the extinction series. If the above reasoning is valid, 16 reinforced trials would now be expected to lead not only to more rapid response at the end of acquisition, but also to greater resistance to extinction than would follow 8 reinforcements. It will be shown that this suggested explanation of the original results is confirmed only in part; although the inter-group differences in extinction-resistance are now too small to be considered reliable, the 16-reinforcement group does not exhibit the predicted superiority in extinction with relation to the 8-reinforcement groups.

The design of the experiment also allowed observations to be made regarding the function of retention over the 24-hour interval. The problems of retention and forgetting are of importance for the complete theoretical description of the learning process that is the ultimate goal of the investigations employing this particular learning situation (*cf.* **2**, **3**, **8**, and especially **5**). Gagné (**4**) studied the changes in response pattern occurring with passage of time varying from 1 to 28 days, finding that retention decreased progressively with lengthening interval, forgetting 'approaching completion 4 weeks following original acquisition' (p. 303). The theoretical application of his results, however, may be limited by the fact that an extinction series preceded (either immediately or indirectly) the 'retention' period. The data secured following the 24-hour interval are, in fact, more a measure of spontaneous recovery than of retention. It is possible, moreover, that varying conditions of reinforcement during original acquisition may be followed by significantly different forgetting functions. Further, as Gagné suggested, the adoption of

criteria of retention other than latent period may lead to somewhat divergent conclusions. It is of interest, then, to note in the present investigation the latent period and running time of the first response following the 24-hour interval, for the 4 groups of rats subjected to different patterns of reinforcement during the acquisition series. It will be shown that the measures of response of the 3 groups receiving 8 reinforced acquisition trials were of the same order of magnitude immediately following the retention interval as on the last acquisition trial, which directly preceded the interpolated period. The rats of the 16-reinforcement group, on the other hand, responded with significantly longer latent period and running time after the 24-hour interval than before, demonstrating a relatively marked degree of forgetting.

Apparatus and Procedure

The apparatus and general procedure were described in some detail in the previous paper (1). The response pattern studied was the traversal of a simple elevated runway, 3′ long and $1\frac{1}{4}$″ wide, which connected starting box and food box. The strength of response in any trial was measured in terms of latent period (the time elapsing between the opening of the starting box door and the rat's crossing of a line 4″ down the runway) and the running time (the time elapsing between the crossing of the 4″ line and entrance into the food box). Reinforcement, when appropriate, was given in the form of a small Purina chow pellet, placed in the back of the food box before the beginning of the trial. Four preliminary daily sessions preceded the experimental session, to acquaint the animal with the type of runway and reinforcement used in the test trials.

The schedule of acquisition trials for the 4 groups of rats was as follows:

Group I—100 percent reinforcement: 16 reinforced acquisition trials. Inter-trial interval of 75 seconds.

Group II—50 percent reinforcement: 16 trials, 8 reinforcements. Reinforcement was given at the end of trials 1, 2, 4, 6, 9, 11, 12, and 15. Inter-trial interval of 75 seconds.

Group III—100 percent reinforcement: 8 reinforced trials. Inter-trial interval of 75 seconds.

Group IV—100 percent reinforcement-spaced: 8 reinforced trials, temporally spaced to correspond to the reinforced trials of Group II. The inter-trial interval thus varied between 75 and 255 seconds.

These 4 groups may be designated, respectively, as 16/16, 8/16, 8/8, and 8/8-S, with the denominator representing the total number of acquisition trials, the numerator the number of reinforced trials, and S referring to the increased average inter-trial spacing.

Immediately following the last acquisition trial the animal was placed in a neutral cage for 1 hour with water, but no food. He was then placed for 15 minutes in a feeding cage, which in addition to the water supply contained a large number of Purina pellets somewhat larger than those used in the experimental session proper. At the end of this time the rat was returned to his living cage (without food). Twenty-four hours following the end of the acquisition series the extinction series was begun. All rats were treated similarly during these trials, with no reinforcement by food given and the inter-trial interval 75 seconds. Each animal was run until that trial during which the response of leaving the starting box failed to occur within 3 minutes. This was arbitrarily taken (as in the earlier experiment) as the point of 'complete' extinction.

The experimental routine was thus such as to allow the examination of the course of acquisition of the running response under 4 conditions of reinforcement, the retention of the response by the 4 groups after a 24-hour interval, and the course of extinction following the 24-hour interval.

The Animals.—Each group consisted of 13 male albino rats from the laboratory colony, none of which had had any training prior to this experiment. The rats were drawn from 5 litter-groups (each of which was composed of siblings and double first cousins) and averaged 70 days of age at the time of the acquisition series (range, 60 to 80 days). The animals were

selected in such an order that the 4 groups were matched with respect to age and litter. Examination of the average response time of the 4 groups on the first 2 experimental trials indicated that no significant difference in response tendency existed among the groups prior to their differential treatment during acquisition.

Results

In Table 1 are presented the average latency and running time data of the 4 groups for the acquisition series and for the first 10 trials

TABLE 1

Average Log Latent Period and Log Running Time of the 4 Groups of Rats for the Acquisition Trials and First 10 Extinction Trials

Acquisition Trial	Group I (16/16)			Group II (8/16)			Group III (8/8)			Group IV (8/8-S)		
	N	LLP	LRT	N	LLP	LRT	N	LLP	LRT	N	LLP	LRT
1	13	2.07	1.04	13	2.06	1.03	13	2.03	0.96	13	2.11	1.08
2		1.47	0.61		1.59	0.65		1.42	0.49		1.39	0.64
3		1.18	0.50		1.29	0.50		1.37	0.59			
4		1.13	0.55		1.25	0.66		1.19	0.49		1.20	0.68
5		1.05	0.72		1.20	0.68		1.33	0.64			
6		0.98	0.69		1.18	0.61		1.23	0.60		1.09	0.83
7		1.19	0.58		1.28	0.71		1.14	0.55			
8		1.06	0.56		1.18	0.62		1.02	0.47			
9		0.99	0.47		1.28	0.84					1.01	0.73
10		0.79	0.45		1.20	0.53						
11		0.71	0.46		1.17	0.57					1.06	0.65
12		0.74	0.34		1.22	0.55					1.08	0.65
13		0.84	0.41		1.00	0.49						
14		0.59	0.39		0.70	0.53						
15		0.69	0.38		1.04	0.56					1.07	0.50
16		0.53	0.27		1.04	0.53						
					24-Hour Interval							
Extinction Trial												
1	13	1.04	0.44	13	0.95	0.51	13	1.06	0.50	13	1.08	0.63
2	13	0.96	0.30	13	1.20	0.42	13	0.93	0.37	13	0.88	0.42
3	13	1.09	0.33	11	0.89	0.43	13	0.93	0.40	13	0.89	0.52
4	13	1.40	0.38	11	1.10	0.69	13	1.07	0.47	13	1.19	0.56
5	13	1.32	0.41	11	0.94	0.64	13	1.19	0.66	13	1.26	0.61
6	11	1.23	0.67	11	1.29	0.75	11	1.18	0.43	12	1.27	0.72
7	11	1.26	0.72	11	1.26	0.87	11	1.29	0.73	12	1.29	0.75
8	11	1.43	1.03	11	1.09	0.85	10	0.98	0.50	12	1.35	0.94
9	10	1.39	0.77	11	1.20	0.82	10	0.95	0.67	12	1.40	0.89
10	9	1.37	0.92	11	1.22	0.89	10	1.25	0.78	11	1.51	1.10

of extinction. The response times have been transformed into logarithmic values, as has been done in all the studies employing this runway situation, in order to compensate for the skewness of distribution of the raw scores. The latency data are shown in graphical form in Fig. 1, and the running time curves are given in Fig. 2.

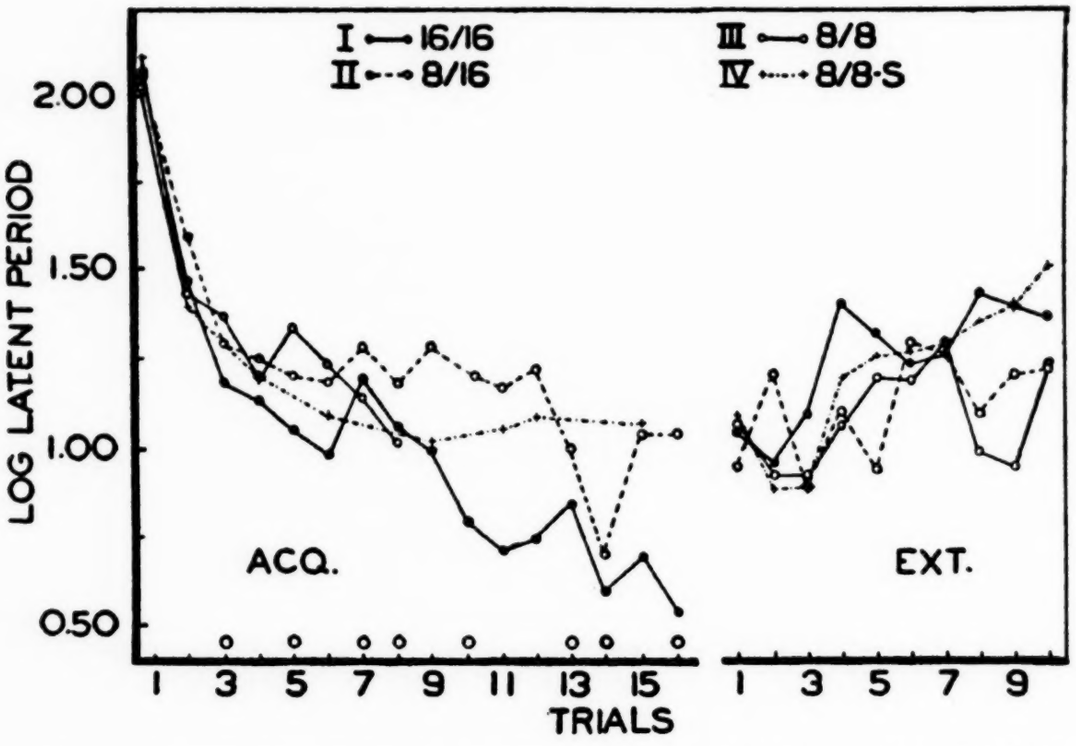

FIG. 1. Average latencies for the acquisition trials and the first 10 trials of extinction. The break in the abscissa indicates the passage of 24 hours. The circles above the abscissa indicate those trials which were not reinforced in Group II.

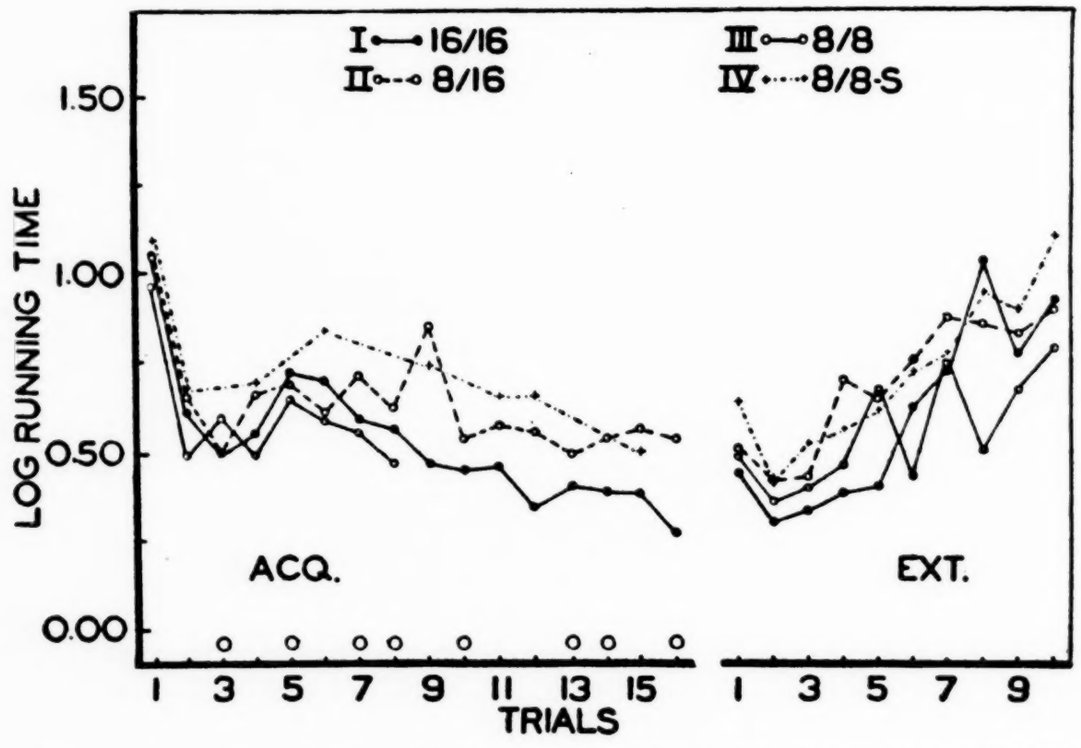

FIG. 2. Average running times for the acquisition trials and the first 10 trials of extinction. The break in the abscissa indicates the passage of 24 hours. The ciphers above the abscissa indicate those trials which were not reinforced in Group II. The second point in the acquisition curve of Group IV has been transposed 0.03 log units upward.

Acquisition.—The latency curves of acquisition differ from the trends previously obtained chiefly in that they decline somewhat more gradually, and never reach as low final levels. All 4 curves begin just above 2.00 log units (117 sec.) and drop to 1.40–1.60 log units on the second trial. Thereafter the progress is a function of the amount and pattern of reinforcement. As may be seen in Table 1, the final level of acquisition depends on the absolute amount, rather than the pattern of reinforcement. Group I (16/16) responds with a log latency of 0.53 (3.4 sec.) on trial 16, while the 3 groups receiving 8 reinforced trials respond in about 1.05 log units (11.2 sec.) on their last acquisition trial. None of the differences among the latter 3 groups is significant, but each of the 3 group averages differs significantly from the Group I figure ($P \leqq 1$ percent).

The curves for log running time (Fig. 2) show no characteristic markedly different from the latency curves. All curves start at about 1.00 log unit, drop for 1 or 2 trials, rise briefly but definitely (beginning on trial 3 or trial 4), and drop again toward the final level. As in the latency curves, the final acquisition level seems to depend more upon the total amount of reinforcement than upon the number of trials or the proportion of reinforcement. The running time averages of Groups II (8/16), III (8/8), and IV (8/8-S) are not significantly different from each other (about 0.50 log units or 3 sec.), but each is reliably higher than the mean of Group I (0.27 log units or 1.8 sec.).

Retention.—It is clear that at the end of acquisition Group I was responding with a significantly shorter latency than were the other 3 groups. Examination of Fig. 1 shows, however, that following the 24-hour interval all 4 groups responded with latencies of essentially equal values (on the first extinction trial). The 4 groups are obviously characterized by dissimilar rates of forgetting. As a measure of each group's retention of the habit over the 24-hour interval the last trial in the acquisition series may be compared with the first extinction trial. No great difference in latent period appears between these 2 trials for Groups II (8/16), III (8/8), and IV (8/8-S). It would seem that little detectable forgetting occurred during the interpolated period for these animals. On the other hand, the mean log latent period of Group I (16/16) increases from 0.53 (3.4 sec.) on trial 16 of acquisition to 1.04 (11 sec.) on the first extinction trial. This rise of 0.51 log units, representing the effect of forgetting, is significant beyond the 1 percent level ($t = 4.3$; see Table 2). These results indicate that, within the limits of this experiment, the greater amount of reinforcement during acquisition is associated with the lesser degree of retention after the subsequent interval.

Similar comparisons of running time figures can be made in Fig. 2

TABLE 2

DIFFERENCES BETWEEN LAST ACQUISITION TRIAL AND FIRST EXTINCTION TRIAL

Group	Log Latent Period			Log Running Time		
	Diff.	t	P	Diff.	t	P
I (16/16).....	0.51	4.3	<1%	0.17	3.6	<1%
II (8/16).....	−0.09	0.60	55%	−0.02	0.17	85%
III (8/8).....	0.04	0.19	85%	0.03	0.38	70%
IV (8/8-S).....	0.01	0.08	>90%	0.13	1.6	12%

and Table 2. At the end of acquisition Groups II, III, and IV are responding similarly, Group I significantly faster. On the first extinction trial the average animals of I, II, and III ran with approximately the same speed (the Group IV running time is 0.19 higher than that of I, with a P-value of 2–5 percent). The Group II and Group III averages change very little over the 24 hours, and the increase in the running time of Group IV is significant only at the 12 percent level (t = 1.6). Group I, however, shows a markedly significant running time increase; this 0.17 increment has a t-value of 3.6, indicating reliability beyond the 1 percent level. With the running time measure, as with latent period, the 16-reinforcement group appears to have suffered the greatest loss in learning strength over the interpolated retention period.

Extinction.—The curves of extinction for the 4 groups represent varying numbers of cases at the successive points, due to the progressive dropping out of rats less resistant to extinction (Figs. 1 and 2, Table 1). Thirteen cases are averaged to give the first 2 points of the Group II curve and the first 5 points of the other extinction curves. On the 10th extinction trial 9 animals in Group I responded, 11 in Group II, 10 in Group III, and 11 in Group IV. Because of this changing characteristic of the curves, some of the variations delineated must be interpreted with caution.

The log latent period curves for all 4 groups begin at approximately the same point (0.95–1.08). The Groups I, III, and IV curves drop about 0.14 log units on trial 2 (probably the effect of a 'warm-up' process); the increase in Group II average latency may be attributed in large part to slow responses by 2 animals (it is significant, however, at the 5 percent level). The latency increases on the 3rd, 4th, and 5th trials may suggest that extinction is taking place somewhat more rapidly in Group I than in the other groups, while Group II is extinguishing least rapidly. These inter-group differences, however, are of much smaller magnitude than were those obtained in the previous study (1, Fig. 2): the interpolation of the 24-hour period before extinction decreases the differences in

initial extinction rate among the groups given different patterns of reinforcement. As in the earlier experiment, relatively little latency increase occurred between trials 5 and 10 (with the possible exception of the Group IV rats).

The log running time curves of the 4 groups start at slightly different points: I responded with the fastest, and IV with the slowest running time. All curves drop to the second point and then gradually rise, with somewhat fewer irregularities than appear in the latency curves. The slopes of the 4 curves differ very little from one another, and the relationships among the group averages are not very greatly different on the 5th and 10th trials from those obtaining on the first 2 trials. The criterion of running time, then, shows slight deviation in rate of behavior change among the differentially-trained groups when reinforcement by food is completely withdrawn.

Of perhaps greater interest than the slopes of the response time curves is the comparative resistance that the 4 groups exhibit to 'complete' (3-minute non-response) extinction. It was this criterion which in the previous study most clearly differentiated the groups (1, Table 1); those animals having had 16 reinforced acquisition trials continued to respond for fewer extinction trials (15.2) than did those rats having been given only 8 reinforcements during acquisition (Group II = 27.1, Group III = 23.8). Table 3 shows that the inter-

TABLE 3

AVERAGE NUMBER OF EXTINCTION TRIALS REQUIRED TO REACH THE CRITERION OF 3-MINUTE NON-RESPONSE

Group	Condition	N	Trials
I	16/16	13	15.9
II	8/16	13	15.5
III	8/8	13	19.9
IV	8/8-S	13	17.7
	Difference	*t*	P
I-II	0.4	0.13	90%
III-I	4.0	0.85	40%
IV-I	1.8	0.55	60%
III-II	4.4	0.94	35%
IV-II	2.2	0.67	50%
III-IV	2.2	0.46	65%

polation of the 24-hour period between acquisition and extinction abolished these significant differences. Group I (16/16) required 15.9 trials to reach the extinction criterion, Group II (8/16) 15.5 trials, Group III (8/8) 19.9 trials, and Group IV (8/8-S) 17.7 trials. The *t*-test indicates that none of the intergroup differences is statistically reliable. It is illuminating to note that Group II, which required

the greatest number of trials to reach the non-response criterion when extinction immediately followed acquisition, needed the fewest trials to reach the same criterion when the extinction series was delayed 24 hours.

The results may be summarized as follows: in comparison to the three 8-reinforcement conditions, the 16-reinforcement group showed (1) a more advanced final level of acquisition (as measured by latency and running time), (2) greater loss of habit-strength during the 24-hour retention period, and (3) a similar rate of extinction.

Discussion

The data obtained during the acquisition series confirm the trends demonstrated in the previous study: final acquisition level under these circumstances is dependent upon number of reinforced trials, rather than upon the total number of trials given, ratio of reinforced to non-reinforced trials, or temporal spacing. If Group II (8/16) reaches a final level lower than that of Group III (which is questionable) [2] the slight added advantage of this condition may be attributed to the secondary or sub-goal reinforcement furnished by the empty but familiar feeding box on the 8 non-reinforced trials (*cf.* **9**). Somewhat slower acquisition rates obtained in the 4 groups than characterized the corresponding animals in the previous experiment, and as a consequence the latencies at the end of acquisition were slightly higher.[3] Nevertheless, the relative positions among the present groups during acquisition are not altered by this difference. If the inter-group relationships during extinction are now found to deviate from those found in the earlier study, such differences may be attributed to the interpolation of the 24-hour interval before extinction.

Before the effect of the interpolated period upon extinction can be interpreted, the differential retention values of the various groups must be considered. It is clear that the apparent retention, based on comparison of the latencies of the last acquisition trial and the first extinction trial, is approximately perfect in Groups II, III, and IV, while there is a significant loss in Group I. But two complications arise when this comparison is made the basis for the measurement of retention. In the first place, this measure ignores the effect upon learning strength of the reinforcement involved in the last acquisition trial: had not the 24-hour period been interpolated, the

[2] A comparison of averages of the last 3 acquisition trials yields a difference in favor of Group II of 0.17 log units, significant at only the 16 percent level.

[3] The differences between the 2 experiments in the acquisition rates characterizing the various groups are not great; final acquisition levels differ to the extent of 0.05 to 0.17 log units. These slight deviations in absolute values may be due to age and litter differences.

latency of the first extinction trial would probably have been shorter than that of the last acquisition trial (at least for the 16/16, 8/8, and 8/8-S groups). A more accurate estimate of retention would be based on comparison of this hypothetical point immediately following acquisition, and the first extinction trial. The closest approximation to this point can be obtained by subtracting from the log latent period of the last acquisition trial the drop that followed this trial for the corresponding group of the previous experiment (1). The corrections thus calculated [4] are greatest for Groups III and IV, yielding hypothetical levels of 0.93 and 0.92, respectively, instead of 1.02 and 1.07. If it is valid to adopt this corrected final level as the point of departure, the log latent period losses over the 24-hour period may be summarized as: Group I (16/16), 0.50; Group II (8/16), − 0.09; Group III (8/8), 0.13; Group IV (8/8-S), 0.16 (*cf.* Table 2). This treatment would indicate that there was probably some decrease in retention in Groups III and IV, but the amount of forgetting, both relative and absolute, is still unquestionably the greatest for Group I.

The second factor distorting the retention picture is that involving the 'warm-up' phenomenon. Many work curves and retention curves demonstrate this effect, which operates to make the first response (or first several responses) of a session abnormally slow or small in comparison with immediately following trials (*cf.* **10**, p. 116). From this it would be expected that the true level of retention after the 24-hour interval should be represented by shorter response times than those actually recorded on the first trial. On the basis of the extinction curves of the previous study, the second point in extinction would be predicted to be higher than the first point, rather than lower, as is the case in 7 of the 8 present curves. This discrepancy may with some justification be explained by the assumption that the first point on the extinction curve is spuriously high, due to the 'cold' condition of the rats at that time. Readjustment of response times on the basis of the 'warm-up' concept would therefore involve the lowering of the first point on the response time curves following the 24-hour interval, and would thus tend to increase the retention scores. But such treatment would be cancelled out by the contrary rectification based on the learning effect produced by the last acquisition trial (see previous paragraph). Thus it may be that the most satisfactory evaluation of retention and forgetting is to be obtained from the direct and uncorrected comparison of the last acquisition trial and the first extinction trial. Whatever the case, the conclusion is clear that little forgetting of the response pattern occurred in 24 hours following the conditions of 8 reinforcements (Groups II, III,

[4] To compensate for trial-to-trial variability the average of the last 2 acquisition trials is used, rather than the last point in the curve.

and IV), but that considerable forgetting took place following the acquisition condition of 16 reinforced trials (Group I).

An explanation for the differential retention functions following the various reinforcing conditions is not immediately apparent. Partial loss of habit efficiency with passage of time is a typical experimental result, and so it is not surprising that the Group I response times showed significant increases over the 24-hour period. But that this clear-cut forgetting should occur in Group I (16 reinforcements) while those groups having received *less* reinforcement during acquisition present pictures of near-perfect retention is certainly contrary to usual findings, and calls for further analysis of the phenomenon. It is as if some factor were operating to produce a 'floor' effect following the retention period, a factor making impossible response faster than some minimum value. If such is the case, the relatively complete retention demonstrated by the 8-reinforcement groups represents the normal course of the excitation-inhibition interplay, and the relatively great extent of forgetting exhibited by Group I is due to the retarding influence, after the interval, of the 'floor.' Whether or not this minimum level is a function solely of the forgetting process cannot be decided at this juncture. It is possible that it is inherent in the particular response required of the rat, or is due to the spontaneous recovery of the original aversion to the exposed and lighted runway (extinguished during pre-training and during the acquisition series). It will be of interest to ascertain by further experiment if this postulated 'floor' is the same for groups reinforced in different amounts and patterns during acquisition, with the retention period constant, and for groups with equivalent acquisition treatment (equal final levels) tested after varying retention intervals. In this manner it may be determined whether the loss occurring over varying periods is dependent more directly upon final acquisition level, or elapsed time, or is a characteristic of the type of response itself.

Examination of the 4 latent period curves indicates that the slopes during extinction are not significantly different following the several patterns of training. It would seem that the interpolation of the interval between acquisition and extinction acted to make the once-divergent groups more similar. This is more understandable when it is recalled that the first point of the extinction curves is approximately the same for the 4 groups, due to the differential retention scores. In the previous study the group curves approached a common range of values between the fifth and tenth trials, and the divergent steepness of the early slopes thus depended upon the different levels of the initial points.

When a further comparison is made of the extinction curves

obtained in the two studies, it becomes apparent that the interpolation of the retention interval decreased the slope of the curves for *all* groups. This appears to confirm in part the formulation previously suggested. This postulation was to the effect that reinforcement involves an 'inhibitory' process as well as an 'excitatory' effect. The size "of the inhibitory increment produced by any extinction trial might conceivably be proportional to the amount of inhibition already present" (1, p. 66). But this inhibition is dissipated with passage of time. Therefore, after the 24-hour interval less 'inhibition' should remain in the system, subsequent extinction trials should add proportionately smaller inhibitory increments, and thus the curves of extinction should rise less steeply. And such is seen to be the case.

When the inhibitory effect of reinforcement was postulated, it was thought that the most clear-cut test of the hypothesis would involve comparison of the total number of extinction trials required by the various groups to reach the 3-minute criterion of non-response. When extinction followed acquisition immediately, it required 15.2 trials for Group I to reach the criterion, 27.1 for Group II (8/16), and 23.8 for Group III (8/8). It was predicted that passage of time would allow dissipation of the inhibition, and Group I would then resist extinction longer than would the 2 groups having had 8 reinforcements, due to the greater amount of excitation present in the former. This was not found to be the case, and so either the suggested formulation is an incomplete explanation of the phenomenon, or the experiment is only a partial test of the postulation. And yet the change that occurred was in the predicted direction, for the interpolation of the period raised the extinction-resistance of Group I to statistical equality with the other 3 groups. This suggests that the formulation is at least partially valid, and that more extensive variation of the several parameters might lead to still greater resistance in Group I, and in this way confirm the hypothesis more fully. Of course, it may eventually prove to be that a relatively small number of reinforcements (*e.g.*, eight) leads to the maximum possible resistance to extinction, and that no amount of over-learning can raise this limit. But before such a conclusion can be accepted, further manipulation of the amount of reinforcement during acquisition, and the temporal relationships between acquisition and extinction, is indicated.

Summary

This experiment was designed to test the validity of one suggested explanation of results previously reported.

Four matched groups of 13 rats each were tested in a learning situation involving a simple running response, with latency and

running time the measures of strength of response. The conditions of acquisition were:

Group I—100 percent reinforcement: 16 reinforced trials.
Group II—50 percent reinforcement: 16 acquisition trials, 8 of which were reinforced, in a predetermined random order.
Group III—100 percent reinforcement: 8 reinforced trials.
Group IV—100 percent reinforcement, spaced: 8 reinforced trials spaced to correspond temporally to the reinforced trials of Group II.

An extinction series was begun 24 hours after the end of the acquisition series.

1. The response times of the three 8-reinforcement groups reached approximately identical levels by the end of the acquisition series; the response times of the Group I animals were significantly shorter.

2. Comparison of the last acquisition trial and the first extinction trial suggests that 24-hour retention was nearly complete in Groups II, III, and IV (8 reinforcements). The increase in response time for Group I (16 reinforcements), on the other hand, indicates a significant loss of retention for this group.

3. Seven of the 8 curves demonstrated the 'warm-up' phenomenon between the first and second trials of extinction.

4. The initial slopes of the extinction curves were not greatly different for the 4 groups of this experiment. All (especially those of the Group I curves) were less steep than the slopes of the corresponding curves presented in the previous study (1), in which extinction started immediately after acquisition, rather than 24 hours later.

5. The number of extinction trials required to reach the criterion of 3-minute non-response was not significantly different in the 4 groups, a finding in contrast to that of the previous study.

The theoretical implications of the results are discussed. It is concluded that the earlier postulation of an inhibitory effect of reinforcement is partially confirmed, for the interpolation of the interval preceding the extinction series increased the relative resistance to extinction of Group I (explicable in terms of dissipation of the reinforcement-inhibition during the interval). This interpretation, however, is complicated by the unusual finding that the greater amount of reinforcement (in Group I) was followed by relatively less 24-hour retention than marked the groups receiving fewer reinforcements during acquisition. Further experimental manipulation of the various parameters appears requisite for an understanding of the processes involved in the situation.

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THE EFFECT OF PRACTICE UPON THE PERCEPTION OF SIMPLE DESIGNS MASKED BY MORE COMPLEX DESIGNS[1]

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The Problem

The present experiments were suggested by the studies of Gottschaldt (**5**, **6**, also in **3**) on the influence of past experience upon the perception of form. Much controversy has arisen as a result of these papers. Koffka (**8**), Köhler (**9**) and other Gestalt psychologists have placed great emphasis upon his results in arguing against the effect of past experience in our seeing definite form. On the other hand many have raised their voices in objection to his conclusions and to the interpretation which Gestalt psychologists have placed upon his findings.

Gottschaldt's experiments have been discussed so much that it is scarcely necessary to review them here. He concludes that bare repetition has no effect on perceptual organization. However he does find that when his subjects were instructed to look for the simple designs they improved greatly as a result of this kind of repetition. Koffka (**8**, p. 396) says in reviewing Gottschaldt's work: "Clearly the search attitude has some influence, whereas mere repetition has none whatever, but equally clearly in the majority of cases the forces corresponding to this search attitude are not sufficient to overcome the internal forces of organization within the figures. However, attitude may have an effect upon organization, an effect which is not reducible to experience." Thus there is the denial of the automatic effect of past experience and a limited acceptance of the effect of directed practice—the effect being attributed to the attitude of search rather than to past experience. Several recent papers, especially Djang (**1**) and Henle (**7**), have presented evidence indicating that bare repetition is not without effect. Henle has shown

[1] The author is deeply indebted to Professor R. S. Woodworth of Columbia University for guidance and stimulation in the early stages of this study which began at Columbia over six years ago. The designs used are an elaboration of Gottschaldt's original designs (**5**) and were prepared by Professor Woodworth for use in the laboratory. Experiments II, III, and IV were done in the laboratory of New Jersey College for Women with the assistance of Misses Mildred Hubeny and Eileen Link. They were begun in the spring of 1939 and concluded in the spring of 1940. The author reported on the results before the Eastern Psychological Association at Atlantic City in the spring of 1940.

experimentally that her results cannot be attributed to the search attitude. Other experiments dealing with this general problem have recently been reviewed and evaluated by Woodworth (**10**).

The present experiments might be considered as an amplification of Gottschaldt's experiments in which he uses the search attitude. The problem of how the subject overcomes the influence of masked contour has not been studied. It is largely to this end that the present studies have been designed. We are interested then in measuring the effect of repetition as in the usual learning experiment; the effect of varying the time interval between trials, transfer of training, and a comparison of the effect of general versus specific experience.

Material and Procedure

Material.—A sample of the designs used in this experiment is reproduced in Fig. I. The 8 simple designs are reproduced in the first column and three samples of each series of complex designs appear in the remaining columns. The number accompanying each complex design refers to its rank in difficulty based upon the median time taken by 10 *Ss* on their first trial to find the simple design. A rank of 8 indicates that the design is the most difficult of the series. It is not indicated in Fig. I, but it should be borne in mind, that there are three each of the E and the F series. Thus the material consists of 12 complex series of 8 designs each. From one to three (mostly two) of the complex designs do not contain the simple design. The purpose of the additional E and F series of complex designs is to measure the effect of specific versus general practice (see Exp. IV).

General Procedure.—The specific procedure for each of the four experiments will be described below. The material was presented to each *S*, one design at a time. The designs were blue prints and a little over twice the size of the samples in Fig. I. Timing was done by means of a stopwatch to one-tenth of a second. As the design was presented to the subject, the watch was started, and it was stopped as soon as the subject responded. This method of timing is not too accurate for the individual design, but is fairly accurate for the comparative purpose for which it is used.

Statistical Treatment of Results.—All correlations reported below are computed by the rank-difference method. Since the groups are small the standard error of the mean is computed using N-1 (**4**, p. 201). The standard error of the difference between two correlated means is used where the correlations are significant (**4**, p. 218).

Preliminary Experiment I

The purpose of this experiment is to measure the effect of repeating the process of finding the simple design in the complex design, and to get some introspections concerning the learning process.

Subjects and Procedure.—There are three female subjects: two of them graduate students in psychology at Columbia University, and the third, a college graduate who had not majored in psychology. The material as described above, consists of twelve series of eight complex designs each. In this experiment, however, the designs which did not contain the simple design were not included. In all there are 71 complex designs and 8 different simple designs. The task set the *S* is described in the instructions:

"I am going to show you a simple design. Look at it carefully. I want you to find this design in the complex designs which I am going to show you. It will be in each one of them. As soon as you find it say *yes* and then point to the location of the design. The concealed design will be exactly the same size as the sample which you see before you, and will be in the same spatial orientation. All of the lines must be present and observed as a complete design before saying *yes*."

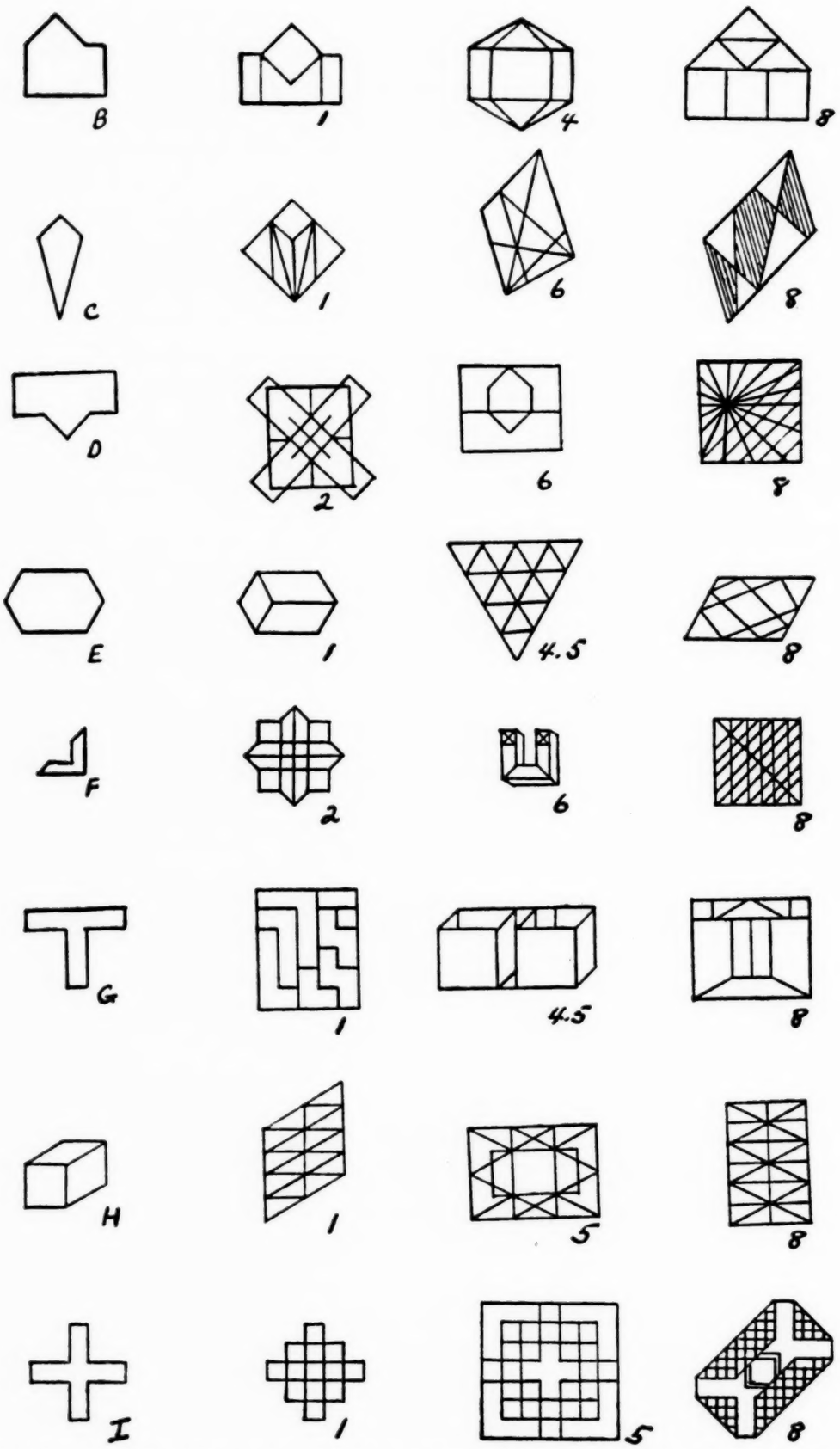

FIG. I. A sample of the designs used in this experiment. The first figure in each row is the simple design, followed by three samples of the masking designs. The numbers refer to the rank order of difficulty, based upon the median response time of ten *S*s. A rank of 8 indicates that a design is the most difficult in the series. Designs F-8 and H-8 do not contain the simple design.

An error was counted against the *S* if the simple design could not be found in three minutes, or if upon pointing out the design, the *S* pointed to the wrong place. Practically all of the errors were of the latter type. In no case was the subject told whether or not he had pointed to the correct location. Thus any improvement in the later trials cannot be attributed to this source. One trial consists of going through the twelve series (71 designs) once. The trials followed each other as indicated in Table I.

Results of Experiment I.

TABLE I

SHOWING FOR EACH OF THE THREE SUBJECTS THE TOTAL TIME IN SECONDS AND TOTAL ERRORS PER TRIAL, AND THE TIME WHICH ELAPSED BETWEEN TRIALS

Trial	Subject W			Subject L			Subject B		
	Elapsed Time	Total Time	Total Errors	Elapsed Time	Total Time	Total Errors	Elapsed Time	Total Time	Total Errors
1		710	11		454	17		507	21
2	1 day	386	16	1 day	349	7	1 day	391	7
3	2 days	359	10	9 days	288	9	2 days	338	6
4	9 "	289	5	90 "	218	7	3 yr.	262	1
5	30 "	263	4				3 yr.	125	1

All three *S*s show the effect of practice. There is a substantial decrease in both time and errors. Individual differences are noted. Subject W (see Table I) took a great deal more time on the first trial than did the other two *S*s, but apparently she worked more carefully for she made fewer errors. On the second trial she concentrated too much on reducing her time and as a result her error score shoots up. From this trial on there is a gradual decrease in both time and errors. Subject L was motivated chiefly by the time factor. After the second trial there is not much change in the number of errors but there is a substantial decrease in time.

Subject B shows the greatest drop in errors, having started with the greatest number and reaching the lowest level. The remarkable thing about this *S*'s record is that three years after the third trial, during which time she had not seen the figures, she shows a substantial decrease in both time and errors. Again three years after the fourth trial, under the same conditions, she shows another substantial decrease in time. Again she makes one error (pointing to the wrong location) but not the same error which she had made three years before. It should be added here that this is the subject who was not specializing in psychology, hence her improvement in score cannot be attributed to contact with reference to Gottschaldt's or other similar material.

The verbal reports of the *S*s throw some light upon factors which operate in improved facility at this task.

Subject W. "After the first trial I didn't bother so much with the figure as a whole but looked for the important parts. Once I

found the important parts the rest of the design seemed to come quite easily although some of them never appeared as a figure which stood out clearly. These I had to trace out with my eye. Others flashed out as soon as I looked at them. As I went along I seemed to know better where to look for the important parts."

Subject L. "My attitude toward the task has changed. Now I look for the essential parts rather than at the figure as a whole. If these essential parts are not there I don't look any further."

Subject B. "I see it in a flash or I find a side, an angle, and trace the other parts with my eye. Sometimes I have to make several starts. I squint for the complicated ones. This seems to allow me to close out the unessential parts. When I see it (the simple design) the lines often look more distinct than the other lines of the figure."

The above results show that the *S*s learned to find the simple figures embedded in the complex ones with a great deal of facility. It is surprising to note the little effect that different amounts of elapsed time between trials apparently have upon the amount of improvement shown. One might expect that after a long period of time the performance would not be as good and certainly little better than the previous trial. There is a continued drop in time and errors after a month, three months, and even three years. From the results it would be impossible to judge in which case a trial followed the previous one by a day, or by a month or more. It would appear that the amount of experience is the important factor and that the amount of elapsed time between trials matters little. This question is put to a more systematic test below.

Experiment II

The purpose of this experiment is to make a systematic check upon the first experiment, using more subjects and an equal amount of elapsed time between trials for each *S*.

Ten *S*s went through the eleven series of figures three times. The second trial followed the first by twenty-four hours and the third followed the second by two weeks. In this experiment, and in the two below, Series F-3 had to be omitted because it was not available. In addition to the complex designs which contained the simple designs, from one to three cards which did not contain the simple designs were added to each series. This brought the total of each series to eight complex designs. The additional designs were added in order that we could do away with the checking of each response.

Another question raised in this experiment is the problem of the effect of practice upon the number of simple designs which immediately stand out upon viewing the complex design. In the first experiment it was quite apparent that the subjects were seeing more simple designs immediately upon the presentation of the complex

designs as the experiment progressed. Since Gottschaldt states that directed practice has no such effect we thought it worth while to check this finding. The directions to the *Ss* will bring out more clearly the plan of this experiment:

"You are to be shown some series of geometrical figures. For each series there will be a simple design and eight complex designs. Some of the complex designs will have the simple figure concealed in them and some will not. The complex designs will be shown to you one at a time and you are to look at each carefully and to decide whether or not the simple design is concealed in it. As soon as you have decided say *there* or *not there*. If it is *there* you are to give your answer one of three classifications: (1) the simple design appears to stand out immediately, (2) the simple design, although not seen immediately, springs out as a whole after a few seconds study, and (3) the simple design is difficult to see as a whole even though you know its location. The concealed design will always be the same size and in the same spatial relation as the simple design before you. All lines must be continuous, but they may be crossed by other lines or be a part of a longer line. Remember all parts of the simple figure have to be present."

These same instructions are used for the remaining experiments of this paper. Each subject is tested in the presence of two *Es*. The *Ss* are all students at New Jersey College for Women, and range in age from 18 to 22 years.

Results of Experiment II.—Three measures of performance are taken: total time (the sum of the times taken for the responses to each individual design in the twelve series), the total number of errors, and the total number of responses taking two seconds or less. The correlations in Table II show the consistency of the measures

TABLE II

RANK-DIFFERENCE CORRELATIONS SHOWING CONSISTENCY OF RESPONSE FROM TRIAL TO TRIAL FOR TIME, FOR ERRORS, AND FOR THE NUMBER OF RESPONSES REQUIRING 2 SEC. OR LESS, AND RELATIONS BETWEEN THESE MEASURES. N = 20

Consistency	Total Time	Total Errors	Responses 2 sec. or Less
Trials 1 and 2	.75	.54	.84
" 1 and 3	.67	.03	.69
" 2 and 3	.94	.66	.94

Relation between Measures	Total Time and Total Errors	Speed (Total Time) and Responses 2 sec. or Less
Trial 1	.06	.87
" 2	−.20	.89
" 3	.03	.94

from one trial to another, and relations between these measures. It will be noted that the error score shows less consistency than the other two measures. Although the correlations between Speed and Responses 2 sec. or Less are high, we have good reason for using both measures.

The results of our *Ss*' classifying of responses into three classifications turned out to be quite unsatisfactory. Although our *Ss* do show a consistent increase in the percent of No. 1 responses from Trial 1 to Trial 3 (49, 55, and 58 percent respectively), it is quite

evident that they are not classifying on the same basis as Gottschaldt's *Ss*. Our Class 1 was intended to be the same as his. Under the search attitude his *Ss* put only 2.2 percent of their responses in Class 1. Of course our *Ss* are working under more favorable conditions: they are searching for only one simple design whereas his *Ss* are searching for one of five. However this difference in conditions cannot explain the discrepancy. It is quite evident upon analysis that our *Ss*, for the most part, are merely making a three-category classification—easy, medium, and difficult. Furthermore their classification tends to become more strict as they progress in the experiment. Often an *S* classifies a response as No. 1 on the first trial, and then on the second trial, with a shorter response time, calls it No. 2. One *S* shows a decrease in the number of No. 1 classifications from Trials 1 to 3 (61, 53, and 48 respectively) although she shows a decrease in both time and errors. Upon further investigation it is discovered that the number of Responses 2 sec. or Less increases from Trial 1 to Trial 3 (24, 31, and 39 respectively). In the light of these facts we decided to tabulate the number of these quick responses and to use this objective measure rather than the subjective classification. Although it is not the same thing as Gottschaldt's Class 1, it is a good measure to have in addition to our other two measures. The line was drawn at 2 sec. because this includes a good portion of the responses classified as No. 1, and gives us enough data from trial to trial to treat statistically. A period of time as short as .5 sec. could have been used, but few cases would have been found on the first trial.

The main results of this experiment are presented in Table III. Although they cannot be compared directly with the results of

TABLE III

MEANS AND STANDARD DEVIATIONS OF TOTAL TIME IN SEC., TOTAL ERRORS, AND RESPONSES 2 SEC. OR LESS FOR 10 SUBJECTS, AND RELIABILITY OF DIFFERENCES FROM TRIAL TO TRIAL

Trial	Total Time		Total Errors		Resp. 2 sec. or Less	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	380.27	158.64	18.4	6.95	25.4	15.77
2	259.50	161.54	15.3	5.08	47.8	24.54
3	214.66	123.28	12.8	5.60	58.7	21.27
Differences and Critical Ratios	Diff.	C.R.	Diff.	C.R.	Diff.	C.R.
Trial 1 to 2	120.77	3.20	3.1	1.58	22.4	5.37
" 1 " 3	165.61	4.17	5.6	1.90	33.3	6.59
" 2 " 3	44.84	2.18	2.5	1.69	10.9	5.21

Note.—Trial 2 follows Trial 1 by 24 hr. and Trial 3 follows Trial 2 by 2 wk.

Experiment I, they do confirm the general findings of that experiment. The two time measures demonstrate genuine improvement with repetition. Although none of the critical ratios for the error score are reliable, there is a decrease of 30 percent from Trial 1 to Trial 3 which shows quite conclusively that the improvement on the time scores is not merely increase in speed at the expense of accuracy. The error score is less stable throughout the experiment than the time scores. It should be noted in this respect that there is no correlation between speed and accuracy (see Table II). The measure Responses 2 sec. or Less appears to be our best objective measure of improvement. The critical ratios for this measure are considerably higher than those for Total Time. Apparently some improvement is taking place on some of the easier designs which is partly masked by the greater variability of the responses as a whole.

Experiment III

The purpose of this experiment is to test the hypothesis suggested above, that the length of time between trials is of little importance in this type of learning. In order to make this test we gave 10 more Ss 2 trials on the same material. The group of Ss in Experiment II had their second trial 24 hours after the first trial. The new group of subjects have their second trial one week after the first trial. All other conditions are the same. Ordinarily we should expect less improvement after one week than after one day. The results are shown in Table IV. It will be observed that the two groups matched fairly well on Trial 1. There are slight differences in the means of

TABLE IV

Means and Standard Deviations of the Scores of the One-day Group and the One-week Group on Trials 1 and 2, and the Differences between the Means

		Trial 1			Trial 2		
		Time	Errors	2 sec. or Less	Time	Errors	2 sec. or Less
One day group	M....	380.27	18.4	25.4	259.50	15.3	47.8
	S.D...	158.64	6.95	15.77	161.54	5.08	24.54
One week group	M....	379.51	16.7	23.2	236.95	11.1	47.1
	S.D...	122.53	5.88	14.43	67.66	5.84	16.35
Difference in means....		+.76	+.17	−2.2	+22.55	+4.2	−.7
Critical ratios.....					.55	2.39	—

Note.—The differences under Trial 1 show how well the two groups are matched, and under Trial 2, the effect of the different intervals of time between Trials 1 and 2. A plus sign indicates that the second group is superior and a minus sign that it is inferior.

the two groups but they are not all in the same direction. The time and the error measures favor the one-week group while the number of responses two seconds or less favors the one-day group. On Trial 2 the direction of these differences is maintained. The one-week group makes a slight gain over the one-day group, but the differences are all unreliable. The measure with the highest probability of a true difference is the error score, and this we have shown to be the least stable of the three measures.

It is quite clear that the longer period of elapsed time between Trial 1 and Trial 2 is certainly no handicap. This experiment serves to strengthen the argument advanced in Experiment I that the time between trials is of little importance.

This experiment also furnishes additional data concerning the reliability of the difference in scores from Trial 1 to Trial 2. The C.R. for the mean difference in Total Time is 5.06; for the difference in Errors, which was unreliable in the former group, it is 2.995; and for the difference in the number of responses two seconds or less the C.R. is 8.05. This certainly leaves no doubt concerning the improvement in scores of our *S*s from Trial 1 to Trial 2.

Experiment IV

The purpose of the present experiment is to test the effect of different kinds and amounts of experience. The material was originally designed to make such a test. In the present experiment we use eight series of complex designs (B, C, D, E-1, E-2, E-3, F-1, and F-2). The E series has the same simple design but different complex designs. The same is true of the F series. In the previous experiments the *S*s have gone through all of the designs two or three times, as in the usual learning experiment. The present experiment is set up more on the order of a transfer of training experiment. We compare groups of *S*s on the E-3 and F-2 series who have had different amounts of previous experience (number of series) and different kinds of experience (general and specific series). General experience means practice in finding the simple design in complex designs where the simple design is different from the comparison or test series. Specific experience means that the *S*s have had experience in finding the same simple design in other series of complex designs.

The method of taking data and the directions to subjects are the same as in the previous two experiments. To keep the conditions constant we continue to have the subjects classify their responses into three classes as described above although we do not use the data. It will be recalled that we use the number of responses taking 2 sec. or less in place of the *S*'s classification because it is found to be more consistent, objective, and enlightening. The subjects used in Experiments II and III will be drawn upon in the comparisons made here. Two new groups of 10 subjects each are used. They are given different amounts of limited experience.

In the comparisons made in this experiment Series B is used as an initial measure of ability of the groups. The correlations reported in Table V justify us in this procedure. The correlation of .94

TABLE V

RANK-DIFFERENCE CORRELATIONS BASED UPON THE FIRST TRIAL BY THE 20 SUBJECTS OF EXPERIMENTS II AND III

Data Correlated	Correlation
1. Correlations based upon total time	
Odd and even series	.94
Series B and total score	.88
" " " Series E-3	.63
" " " " F-2	.65
2. Correlations based upon errors	
Series B and Series E-3	.45
" " " " F-2	.66
3. Correlations based upon responses 2 sec. or less	
Series B and Series E-3	.62
" " " " F-2	.52

between odd and even series shows that the procedure is reliable. The correlation of .88 between Series B and the total score justifies us in using this one series as an initial measure of ability. The correlations between Series B and the Series E-3 and F-2 are used in computing the standard error of the difference.

Results of Experiment IV.—The results of this experiment are reported in Tables VI and VII. In Table VI we compare the

TABLE VI

A COMPARISON OF SCORES OF GROUPS OF *Ss* (10 IN EACH GROUP) ON SERIES E-3 AND F-2 WHO HAVE HAD DIFFERENT AMOUNTS AND KINDS OF PREVIOUS EXPERIENCE

The mean scores for Series B are included to show how well the groups matched on that Series.

Group	Previous Experience		Initial Scores—Series B			Comparison Series—Series E-3		
	Series		Time	Errors	2 sec. or Less	Time	Errors	2 sec. or Less
1	B, C, D, E-1, E-2	M	51.10	1.5	.9	31.45	1.3	3.0
		SD	24.10	1.09	.83	17.25	1.46	1.67
2	B, E-1, E-2	M	48.42	1.6	1.5	39.46	1.7	2.9
		SD	37.36	1.50	1.28	20.16	.78	1.51
3	B	M	50.40	1.8	.8	43.43	2.5	1.5
		SD	12.56	1.69	.81	15.73	1.02	1.12
							Series F-2	
4	B, C, D, E-1, E-2, E-3, F-1	M	51.10	1.5	.9	32.62	1.5	2.3
		SD	24.10	1.09	.83	15.17	1.32	1.55
5	B, E-3	M	50.40	1.8	.8	45.59	2.4	.7
		SD	12.56	1.69	.81	15.14	1.02	.64

TABLE VII

DIFFERENCES AND CRITICAL RATIOS OF GROUPS COMPARED IN TABLE VI

Groups Compared	Total Time		Total Errors		Responses 2 sec. or Less	
	Diff.	C.R.	Diff.	C.R.	Diff.	C.R.
Series E-3						
Groups 1 and 3	11.98	2.42	1.2	2.68	1.5	3.41
Groups 2 and 3	3.97	.75	.8	2.50	1.4	3.58
Series F-2						
Groups 4 and 5	12.96	3.07	.9	2.81	1.6	3.33

average scores of groups of Ss on Series E-3 and F-2 who have had different amounts and kinds of previous experience. For instance three groups of Ss have had different previous experience in coming to Series E-3. Group 1 has had three general series (B, C, and D) and two specific series (E-1 and E-2). Group 2 has had only the initial series and two specific series, while Group 3 has had only the initial series. The three groups are fairly well matched on Series B. Group 2 is a little superior on both time measures but occupies a middle position in the mean number of errors. Group 3 occupies a middle position on total time but is inferior on the other two measures.

Turning to the Comparison Series we find that the scores on all three measures are in the order of the amount of previous experience. Group 1 which has had the most experience has the lowest time and error scores and makes the most '2 sec.' responses; Group 2 which has had the next most experience occupies a middle position, and Group 3 which has had the minimum of experience occupies last place. The differences between Groups 1 and 2, however, are all unreliable. The critical ratios for the differences between Groups 1 and 3, and Groups 2 and 3 are reported in Table VII. The differences are both reliable for the number of '2 sec.' responses. The differences in error score show a high probability of a real difference. The differences in total time are both unreliable although the difference between Groups 1 and 3 shows a fairly high degree of probability of being a real difference (99.2 chances in 100).

Groups 4 and 5 are compared on Series F-2. These two groups have the greatest difference in previous experience and, as we might expect, show clear-cut reliability of difference in their average scores. The comparison of these two groups can also be considered as a check on the comparisons made above. We can conclude that practice in finding simple designs in complex designs enables a subject to make a better score on a new series of designs. It is indicated that although general experience is not without effect, it is inferior to specific practice.

Discussion

In the light of the results of the present experiments we cannot agree with Koffka's statement, as quoted in our introduction, that repetition is not effective in overcoming 'internal forces of organization.' Not only is repetition of the same designs effective in this respect but there is also positive transfer to new simple and complex designs. Gottschaldt (**5**), in discussing his results, says that his *Ss* failed to see the masked designs because of the 'internal unity' of the masking designs. Apparently this 'internal unity' is the same as Koffka's 'internal forces of organization.' The meaning of this concept in connection with Gottschaldt's results is difficult to grasp. Apparently it is a figural characteristic. However, in practice, Gottschaldt defines it in terms of difficulty: the more successfully a complex figure masks a simple figure the more 'internal unity' it possesses. But there are many factors which are responsible for good masking. The most important one is the destruction of contour of the simple design. Woodworth (**10**, p. 640) says: "If a given figure is to be concealed, the rules of the game call for the complete presentation of the concealed figure. . . . A large share of the concealed figure can be *omitted* from the total figure. We can actually *omit much of the contour* of a figure while playing the game and presenting all the lines." He goes on to give a number of rules by which the above process can be accomplished. Examination of the complex designs in Fig. I certainly gives no cue to the meaning of 'internal unity' aside from the particular simple design being concealed. Attributing the effect of practice to change in attitude is not sufficient explanation of our results. We could scarcely conclude that with increased experience the *Ss* become 'more searching.' To be sure the attitude of search is important but the improvement comes with actual searching. We shall now turn to some of the factors which are responsible for the improvement shown in our experiments.

The Effect of Experience.—One of the first things which the *S* is likely to report is that he looks for essential parts of the simple design. With experience he becomes more expert in picking them out. The construction of the complex design is examined, for it is soon discovered that certain lines are added in order to obscure the simple design. In this way he learns many of the tricks in concealing the simple design. One of the best of these is to switch dimensions, *i.e.*, if the simple appears in two dimensions make the complex appear in three, or vice versa. The *S* learns that both have to appear in the same dimension for maximum facility in finding the concealed design. One *S* reports in this respect: "I just look at it until it swings around to the same dimension and then the simple

design usually springs out." Switching of dimensions usually results in illusions. There are many other sources of illusion of size, shape, orientation, etc. It is quite apparent from the comment of the *S*s, and also from the results, that practice serves to decrease the amount of illusion.

As also reported by Duncker (**2**), we find some of our *S*s mentioning that the figure-ground relationship changes with experience. Unessential parts of a complex figure come to be viewed as ground. The 'place to look' in a complex design comes to stand out readily. One *S* reports that the lines of the contour of the simple design often appear heavier than the other lines. A negative attitude toward the complex figure as a whole is adopted and means are found to shut it out. One *S* finds that squinting is a help in this respect. A good many of our complex designs have repeated lines or units. Often the *S* finds the location of the simple design but has difficulty in deciding exactly which is the real boundary. Sometimes this is due to the fact that the discrimination is below the limen of the *S*. With practice the limen is lowered. Again the difficulty is due, as Woodworth (**10**) says, to the fact that *S* is forced to see the parts of the simple figure in direct vision whereas usually parts of the figure are seen in indirect vision.

In the case of the repeated designs some of the improvement can be accounted for by memory of the location from previous trials. The *S*s report that they remember the location of some but that there are more that they do not remember. It is quite evident that memory of previous findings is not responsible for all the improvement for there is a drop in errors as well as in time. Then, too, not always the same errors are made. In Experiment IV, of course, improvement has to be due to some other factor for the same complex designs are never repeated. Thus there are many ways in which experience allows opportunities for improvement in finding simple designs concealed in more complex designs.

Summary and Conclusions

1. There is genuine improvement with practice in finding concealed designs. This is shown by a decrease in time and errors, and also by an increase in the number of responses 2 sec. or less.

2. The amount of elapsed time between trials appears to be unimportant. It appears that the amount of experience is the important factor, and that the benefits of such experience are carried over long periods of time. The one case available for testing after a very long lapse of time, shows substantial improvement at the end of each of two three-year intervals. A check experiment involving

two groups of *Ss* shows that it makes no difference whether the second trial follows the first by one day or by one week.

3. According to the classification of responses made by our *Ss* there is an increase with experience in the number of simple designs which immediately stand out in the complex design. However it is quite evident that this subjective classification is made on a different basis than that of Gottschaldt's *Ss*, and that at least some of our *Ss* are inconsistent in their classification. On the basis of other data, however, it appears that there is an increase in this type of response.

4. There is positive transfer of ability with practice. The greater the difference in the amount of experience between two groups of *Ss*, the greater is the advantage of the more experienced group on a series of new material. Although general experience is not without effect, it is not as advantageous as more specific practice.

5. A number of ways in which practice results in improvement are suggested. Although an active attitude of search is important, it is not sufficient explanation of the improvement in scores shown by our *Ss*. Among the more important factors suggested as responsible for improvement are the following:

a. With practice the *S* learns where to look in the complex for the simple design.

b. Distinctive parts are looked for in the more complicated designs in place of the simple design as a whole.

c. The *Ss* become adept in disregarding the figure in its entirety and analyze it in particular places.

d. The figure-ground relationship changes in many cases—the unessential parts become ground against which the simple design stands out.

e. With practice the amount of illusion present in the complex design decreases.

f. There appears to be a lowering of the limen for discriminating the contour of the simple design from a number of closely repeated lines or units.

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STUDIES IN SERIAL VERBAL DISCRIMINATION LEARNING. II. RETENTION OF RESPONSES TO RIGHT AND WRONG WORDS IN A TRANSFER SITUATION[1]

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INTRODUCTION

The present series of experiments was designed to review critically theories of reminiscence and the efficacy of distributed practice. Most of these theories involve assumptions about the relative retention of right and wrong parts of the learning situation. That is, it has been supposed that rests interpolated at different stages in learning might be beneficial either (*a*) by allowing wrong responses to drop out faster than right or (*b*) by permitting the right responses to grow stronger by a maturation process. Although the first alternative has been generally accepted (*cf.* **3**, **4**, **10**), Wheeler (**11**) and Snoddy (**8**) would appear to favor the second, and experimental evidence has not conclusively decided between the two (**1**, **9**). There is still a third possibility that so far has received no attention. Rest pauses might act beneficially by consolidating avoidance responses to the errors in the situation. There is no specific indication that this could not occur.

So at present, although some difference in retention of the right and wrong parts of the learning task is generally thought to be of importance in explaining reminiscence, there is no evidence to show what difference is actually involved. Even if it were granted that the faster forgetting of wrong responses is the most likely alternative, there is no direct evidence that such a differential exists. Hovland states for instance: "We do not know . . . the relative rate of decline of correct and incorrect associations" (**4**, p. 584).

The reason why this state of ignorance has persisted is that in the usual rote-learning technique the strength of error- and correct response-tendencies cannot be independently measured. The response actually made is the resultant of the tendency to make an error and the tendency to make the correct response. And there is no way of telling how much each contributes to the response made. So the

[1] This paper is a modification of part of a dissertation presented in June, 1941 to the Faculty of the Graduate School of Yale University in partial fulfillment of the requirements of the degree of Doctor of Philosophy. I am greatly indebted to Dr. C. I. Hovland for his many helpful suggestions in the planning, execution, and interpretation of the research.

increase in recall score after a rest might be due to an increase in correct response strength, to a decrease in error strength, or to any suitable combination of rates of forgetting of either.

Such considerations as these make it highly desirable to measure separately the retention of right and wrong responses after different intervals of time. It was with this end in view that the present experiment in the series was designed. The same serial verbal discrimination technique reported earlier (7) was used. The subjects had to learn to pick the right word in a series of pairs of adjectives. After they had partially learned the list, the right words from half the pairs were taken out and combined with new words they had never seen before. The wrong words from the other half of the pairs were likewise taken out and combined with new words. The retention of responses to each kind of word could be tested separately in this way after varying intervals of time between original learning and relearning. The choices after the transfer were determined by the retention of responses to the single word that was transferred. They could not be determined by the word which had been removed. Consequently independent measures could be obtained of the retention of responses to right and wrong parts of a series of partially learned discriminations.

Procedure

The procedure is essentially the same as that reported previously (7). Two lists of 20 pairs of two-syllable adjectives were constructed. All 80 words were selected from standard rote-learning lists and differed in form and meaning as much as possible. The pairs were presented in 6 different serial orders and the words within each pair were alternated from top to bottom from one presentation to the next. Both these precautions were taken to prevent learning the right word from its top or bottom position in the series or in any given pair.

The words to be rewarded in a list were chosen at random from the top and bottom of the series of pairs, and the opposite word in each pair was rewarded for half the subjects so that the results could not be due to differences in the words originally made right and wrong. These two different, reciprocal sets of correct words from each list will be referred to as reward-systems A and B.

A set of 20 new dissimilar adjectives (labelled C) was selected for list 1 and for list 2 to be used as neutral words for relearning. One half of these was combined with the right words from half the original learning pairs. The other half was combined with the wrong words from the other half of the original pairs. In all there were 8 lists made up as follows: 1A, 1AC; 1B, 1BC; 2A, 2AC; 2B, 2BC. In the AC or BC lists half of the words (one in each pair) were new (C words), half carried over from A or B; half of the C words were right (those combined with the wrong words from A or B), and half were wrong. The A and B lists were used only in original learning, the AC and BC only in relearning. An A list had to be used with an AC list and a B list with a BC list.

To cancel out any special effects due to the selection of words to be carried over, the pairs from which the right word had been taken in AC also supplied the right word in BC. Since A and B were reciprocal this meant that a different member of each pair was transferred in AC and BC. Every effort was made in this way to reduce list, reward-system, or position peculiarities that might affect the results.

The pairs in each list were photographed in the six different orders on a continuous film band, the A or B list on one side, the AC or BC list parallel with it on the other. They were presented

by an Argus film projector which was so modified that it automatically exposed a pair of words on a ground glass screen every 2 seconds. The modification consisted chiefly of a solenoid which, when activated every 2 seconds by a Telechron timer, gave a short turn to the sprockets on which the film was fixed. As a result of this movement a new pair of words was instantaneously flashed on the screen.[2]

The method of presentation had three noteworthy features. (1) It provided a rapid method of shifting from the A or B list to the AC or BC list without the subject's knowledge. The pairs from both sides of the film were projected but only those from one side could appear in the small ground glass window at one time. The others were reflected on the wooden screen surrounding the window and cutting off the apparatus from the subject's view. If the A pairs were being presented, a shift could be made to the AC pairs by pushing the projector, which was pivoted in the rear, through a small arc. The movement was noiseless and could be made so quickly the subject was not aware of the change. (2) It included a shutter which terminated the presentation interval by rising near the end of it and blacking out the screen. This feature prevented the subject from delaying his choice too long and provided time enough (about half a second) to inform him on the correctness of his choice. (3) The method made use of a bell as the signal that the word chosen was correct. The bell rang automatically when the shutter was up if the experimenter closed a key. It gave a single ring of constant duration and intensity at the same point in the presentation interval.

During the rest periods a Chicago-type memory drum was used to present colors for naming at a 2-second rate.

The subjects were male undergraduates of Yale University secured through the University Bureau of Appointments and paid for their services. When they arrived on the first day they were given a complete set of instructions described in full elsewhere (6). They were told their task was to pick the right word in each of a series of pairs of adjectives. They would have to guess one word in each pair the first time through the list. Correct guesses would be indicated by the ringing of a bell. They were to try and remember which words rang or should ring the bell and to say those the next time through the list. They were to continue going through the list until they selected the correct word in each pair. After reading the instructions, the subjects learned one of the two lists to the mastery criterion of one perfect trial for practice.

At the beginning of the second session they were told that they were to learn another list just like the first. The list they learned was determined by a counterbalancing procedure which included all eight permutations of the four original learning lists (1A, 1B, 2A, 2B) taken two at a time (one for practice and one for work). As soon as the subject reached the original learning criterion of 15 correct choices out of a possible 20, designated hereafter as OL_2, the A or B list was replaced with its AC or BC counterpart. The subjects were not told that a change was made and there was no outward indication that one had been made.

In the control group the change was made during the 6 second interval between trials and in such a way that it coincided with the instant the shutter blacked out the screen. Learning then continued as before to mastery.

After OL_2 other groups of subjects rested 2 minutes, 20 minutes, and 24 hours. As soon as they reached OL_2, they were stopped and asked to name colors. In the 2 minute condition they named colors for the full period and then were asked to continue learning the list where they had left off. In the 20 minute condition they named colors for a minute after OL_2 and a minute before beginning to learn again. In the intervening time they read current magazines in the experimental room. In the 24 hour condition they named colors for a minute after OL_2 and a minute before relearning and left the laboratory for the intervening period. In all conditions relearning was carried to mastery of one perfect trial.

Each condition was completed by 24 subjects according to a counterbalanced pattern of list presentation which was the same for each condition.

Results

Table 1 shows that the four groups of subjects were initially equated in learning ability. The average number of trials taken to

[2] A photograph of the apparatus with a more detailed description of its operation may be found elsewhere (6).

TABLE 1

ORIGINAL LEARNING SCORES FOR CONDITIONS SUBSEQUENTLY VARYING IN REST INTERVAL BETWEEN LEARNING AND RECALL

Condition (Rest Interval)	N	Trials to get 15 in 20		Correct responses on criterial trial			
				Plus words		Minus words	
		Mean	σ_m	Mean	σ_m	Mean	σ_m
1. 6 sec.	24	9.21	.73	7.67	.20	7.83	.17
2. 2 min.	24	9.88	.96	8.13	.14	7.42	.20
3. 20 min.	24	10.08	.69	7.79	.17	7.75	.20
4. 24 hr.	24	9.38	.91	7.67	.20	8.08	.22

"Plus words" refers to those 10 pairs from which the correct words were transferred to the relearning material.

"Minus words" refers to those 10 pairs from which the incorrect words were transferred to the relearning material.

reach the original learning criterion of 15 out of 20 correct choices was very nearly the same for all four conditions.

The column in Table 1 labelled 'plus words' refers to that group of 10 pairs from which the right words were transferred to relearning and combined with new words. The column labelled 'minus words' refers to the group of 10 pairs from which the wrong words were taken for transfer to relearning. The two groups of pairs are learned equally well on the criterial trial in all four conditions. The average for all conditions for the right word group is 7.82 correct choices, for the wrong word group 7.77. This indicates that the arbitrary division of the lists into two groups was equitable, the pairs in each being of equal difficulty. Consequently any differences found in relearning cannot be due to differences in the initial difficulty of the two sets of pairs.

The recall scores are summarized in Table 2 under two headings, plus words and minus words. The scores under each have the same meaning as in Table 1 except that now the transfer has been made.

TABLE 2

CORRECT RESPONSES ON THE FIRST RECALL TRIAL

Condition (Rest Interval)	Plus words		Minus words	
	Mean	σ_m	Mean	σ_m
1. 6 sec.	7.67	.48	4.17	.37
2. 2 min.	7.71	.56	3.71	.54
3. 20 min.	8.42	.30	4.13	.22
4. 24 hr.	7.42	.40	3.83	.46

'Plus words' refers to pairs containing transferred right words.

'Minus words' refers to pairs containing transferred wrong words.

Since the correct response to a transferred minus word is not to say it, the score in the minus word column is the mean number of new words chosen.

For the transferred right words the recall scores do not show any significant differences among the conditions. There is a slight tendency for recall to improve after rests up to 20 minutes, but it may well be a chance fluctuation. The only certain thing is that no forgetting appeared up through 24 hours. Likewise the mean recall scores for the transferred wrong words show no trend. The differences among the conditions are small and not significant.

Introducing the new words did not noticeably influence the level of learning of responses to the right words. The recall scores do not differ significantly from those on the criterial trial in Table 1. But the effect on the wrong words is striking. There is a significant loss in every condition from the criterial to the first post-criterial (recall) trial. The loss is so great that in every condition the wrong words are significantly less well recalled than the right words and yield a mean number of correct responses significantly below the chance expectancy (5 correct choices in 10).

The explanation of this is that when the new words were introduced, the subjects called out the words they recognized. Since the wrong words were more familiar than the new words, they were called out so often that there was less than a chance number of correct responses. The fact that the wrong words were recognized outweighed any avoidance tendencies to them that may have been learned. Familiarity may, on the other hand, have increased the score on the right words because here the familiar words were correct. In short, familiarity so strongly influenced performance on the first recall trial that any effect rest may have had on the two groups of words is completely obscured.

Familiarity should, however, become of less importance as relearning proceeds, and whatever influence the rest intervals had should be reflected in subsequent measures. That this happened is shown by Table 3 which gives relearning scores. The wrong word

TABLE 3

TRIALS TO RELEARN TO THE CRITERION OF 10 OUT OF 10 CORRECT CHOICES (RL_2)

Condition (Rest Interval)	Plus Words		Minus Words	
	Mean	σ_m	Mean	σ_m
1. 6 sec.	8.71	1.55	16.04	1.57
2. 2 min.	7.83	1.67	12.79	1.36
3. 20 min.	8.17	1.00	14.13	1.14
4. 24 hr.	9.54	1.50	16.92	1.52

pairs are still more difficult in every case than the right word pairs, but differences in the degree of difficulty show up. After a 2-minute rest it took 3.25 trials less on the average to learn the wrong words to the criterion of 10 out of 10 correct choices (RL_2) than it did after the usual six second rest. There is no comparable difference in the plus column although the same trend is reflected. The results are summarized graphically in the lower two curves in Fig. 1. Although none of the differences within either column is significant because of the high variability of the scores, they suggest that the 2-minute rest was of considerable benefit for the subsequent learning of the wrong words but of no benefit in learning the right words.[3]

A more sensitive measure of relearning differences proved to be the number of trials taken to reach the same level of mastery as was reached on the criterial trial of original learning. For example, if a subject obtained 8 correct choices from the right word pairs and 7 from the wrong word pairs on this trial, the number of trials he took to make 8 correct responses to the right words in relearning was recorded and also the number of trials he took to make 7 correct responses to the wrong words. The scores obtained in this way are summarized in Table 4 as RL_1. They show the same results as

TABLE 4

TRIALS TO RELEARN TO THE ORIGINAL LEARNING LEVEL (RL_1)

Condition (Rest Interval)	Plus Words		Minus Words	
	Mean	σ_m	Mean	σ_m
1. 6 sec.	2.33	.65	8.25	1.13
2. 2 min.	2.21	.41	4.88	.72
3. 20 min.	1.79	.27	4.38	.57
4. 24 hr.	2.29	.47	8.13	1.28

Table 3 but the differences in the minus word column between the means of conditions 1 and 2, 1 and 3, 2 and 4, and 3 and 4 are all reliable. The probability that any of these differences could have arisen by chance is less than 5 in 100. The reminiscence effect appears to be reliably present in relearning the transferred wrong words.

There is still the question, however, whether the improvement is localized strictly in the transferred wrong words. The smaller

[3] The critical ratio of the difference between the 6-second condition and the 2-minute condition for the minus words is 2.62 if the distributions of the trials taken by the two groups of subjects to reach a criterion of 8 in 10 correct choices on the wrong word pairs in original learning are matched in terms of means and standard deviations. The probability that a difference this large and in this direction could have occurred by chance is less than 1 in 100 ($P < .01$). Throughout the rest of this paper P-values will have the same meaning as here.

differences obtained between various conditions for the right words might have come from the same distribution as the larger differences obtained for the wrong words. Table 5 was constructed to answer

TABLE 5

COMPARISON OF DIFFERENCES BETWEEN MEAN TRIALS TO RELEARN RIGHT WORDS AND MEAN TRIALS TO RELEARN WRONG WORDS TO ORIGINAL LEARNING LEVEL (RL_1)

	Conditions Compared			
	1-2	1-3	4-2	4-3
Right words				
Difference	.12	.54	.08	.50
$\sigma_{diff.}$	.77	.70	.62	.54
Wrong words				
Difference	3.37	3.87	3.25	3.75
$\sigma_{diff.}$	1.34	1.27	1.47	1.40
Difference (Wrong—Right)	3.25	3.33	3.17	3.25
$\sigma_{diff.}$	1.55	1.45	1.60	1.50
C.R.	2.10	2.30	1.98	2.17
P.	<.03	<.02	<.04	<.03

P is the probability that such a difference in the obtained direction could have occurred by chance.

this question. It presents the differences between conditions for both right and wrong words, their standard errors, and the critical ratios of the differences between them. The size of the critical ratios leaves little doubt that the improvement with rest for the wrong words is reliably greater than the similar but small improvement for the right words.

Figure 1 presents graphically the two relearning measures for both right and wrong word pairs. It shows the typical doubly-inflected reminiscence curve but for the transferred wrong words only. There is an improvement after a 2- and a 20-minute rest for the wrong words and a drop at 24 hours that brings the score nearly back to what it was without rest. There is no forgetting except that relative to the improved scores after rest. The curves for the right words show no special trends.

The results taken together indicate unmistakably that rest intervals up to 20 minutes in length after original learning facilitate relearning transferred wrong words but do not appreciably benefit relearning transferred right words.

DISCUSSION

There are several possible explanations of the major result of the experiment that retention of the two parts of the partially learned

discriminations was differently influenced by rest periods. The simplest is that familiarity produced the relearning as well as the recall differences in the wrong word pairs. That is, familiarity resulted in a tendency to choose the wrong words—a tendency which interfered with the opposing tendency to avoid them carried over from original learning. Such interference may have been strongest

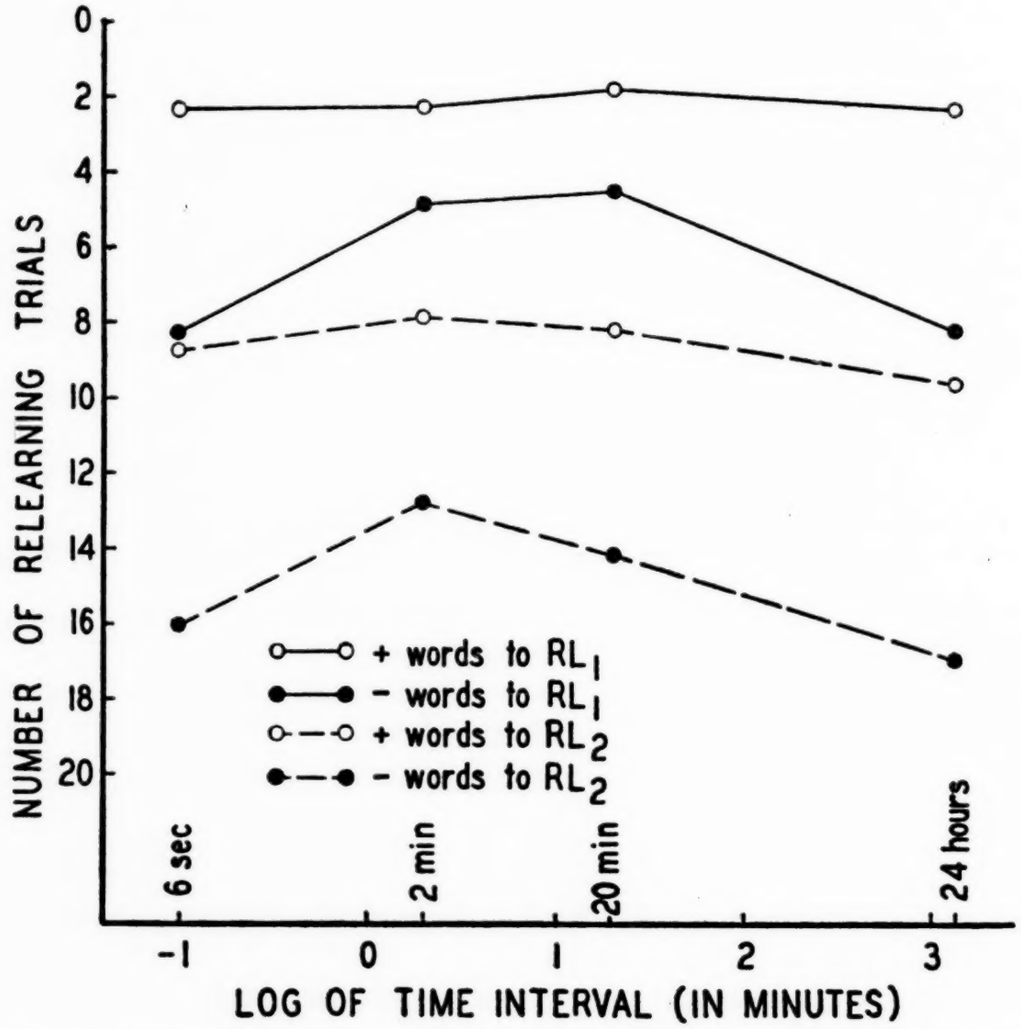

FIG. 1. Mean trials to reach two relearning criteria of correct responses to right and wrong words from original learning for four conditions varying in time interval between original learning and recall. (RL_1—criterion of same number of correct responses to right or wrong words as was obtained on the last trial of original learning; RL_2—criterion of one perfect recitation of all correct responses to right or wrong words.)

immediately when familiarity was presumably greatest, explaining the extreme difficulty of relearning the wrong words after no rest. As time passed the familiarity may have faded sufficiently to 'disinhibit' the avoidance responses to the wrong words—a 'disinhibition' which would have facilitated relearning these words in the new pairs and which would consequently explain the reminiscence obtained after

2- and 20-minute rests. But it would not explain the forgetting from the 20-minute to the 24-hour interval when familiarity should still have been decreasing. To explain this drop the added assumption must be made that by this time there was a loss in the tendency to avoid the wrong words so that even though the interference based on familiarity was completely removed there was net forgetting.

But if this was so, why did familiarity not produce like changes in relearning the right words? The rapid forgetting in familiarity at 2 minutes which has to be assumed to explain the results for the wrong words should have produced a loss in speed of relearning the right words. That is, if familiarity was an important factor in making the right words easy to learn after the transfer, loss in familiarity with rest ought to have made them harder to relearn. But it did not do so. It should also have influenced the recall scores. If (as must be assumed) there was considerable loss in familiarity at 20 minutes, for instance, the recall score of the right words should be lower and that of the wrong words higher than at other intervals. But this was not the case. Since neither of these predictions from the assumption that familiarity was rapidly lost is borne out by fact, the assumption is questionable and the explanation based on it is without much foundation.

If the results cannot be explained as being due to familiarity, what light do they throw on the major question of the relative retention of right and wrong parts of a discrimination? Since they provide separate measures of these two portions of the learned material, they ought to help decide which of the ways in which rest could differentially influence retention is correct. It is possible, first, that rest allows improvement in the retention of the correct portions of the learning material—an improvement brought about by a process variously described as 'primary growth' (**8**) or change in 'maturation level' (**11**). It is assumed here that such maturation would affect primarily what are usually called right responses since errors are eliminated only indirectly as the 'maturation level' increases (**11**, p. 257). In so far as such an assumption is valid there is no evidence of maturation or growth in the rest interval. No reminiscence was obtained for the right part of the discrimination after any rest period. It cannot be objected that the rest was interpolated too late in learning for primary growth to operate (**8**) because reminiscence was obtained (presumably indicating primary growth) at the same stage in practice for the wrong part of the discrimination. Furthermore it is hard to see how this improvement can be explained by a maturation hypothesis which assigns no active rôle in learning to errors.

It is possible that the reminiscence obtained for the transferred

wrong words might have been due to an increase in the tendencies to avoid them brought about in some way by rest. This possibility might be considered an extension to avoidance responses of the maturation hypothesis. To be adequate it must further assume that avoidance responses are affected by rest in a way different from approach responses, since no reminiscence was obtained for the right words. In the absence of any theoretical or experimental basis for such a difference this possibility must be dismissed as highly unlikely.[4]

There remains the possibility that reminiscence is caused by a differential rate of forgetting. The improvement in the wrong words would seem to support this hypothesis. The errors (saying the wrong words) have had an opportunity to drop out during the 2- and 20-minute periods. Consequently the wrong words are said less often, the new words are chosen more often, and reminiscence results. A similar improvement does not occur for the right words after rest as there is nothing to drop out quickly and disinhibit them. It all seems to fit the differential rate hypothesis.

But there is one serious difficulty with such an analysis. As has been previously pointed out (**7**), saying the wrong word in discrimination learning is not an acquired wrong response which can be forgotten in the usual sense. The only acquired response connected with the wrong words is possibly a weak avoidance tendency which would have to get stronger not weaker (as in forgetting) to produce the reminiscence obtained. There is one way, however, mentioned in a footnote previously (**7**), in which wrong associations might be acquired in discrimination learning so that the differential rate hypothesis may be amended to cover the results.

The tendency to choose a wrong word might be increased by generalization with another similar, correct word elsewhere in the list. As the strength of the correct response increased, the generalized tendency to say the similar but incorrect word would also increase. This would fit the requirements of an *acquired* wrong association that could be forgotten during a rest. If it were so forgotten, it might disinhibit the avoidance responses to the wrong words and cause more choices of the new words or the reminiscence actually obtained.

The forgetting of such an acquired generalized response would depend (in the absence of opportunity for differential reinforcement) upon the forgetting of the correct association from which the response generalized. This means that there must be forgetting of the correct associations during those intervals when the more rapid forgetting of responses generalizing from them is utilized to explain reminiscence in the wrong words. But there is no forgetting of the responses to

[4] It has been discussed more fully elsewhere (**6**).

the right words at those intervals when reminiscence appears in the wrong word pairs. Therefore unless some other reason for the lapsing of generalized responses can be found, the explanation of reminiscence in discrimination learning in terms of a differential rate of forgetting is rendered more unlikely than ever.

These arguments are not entirely conclusive because of the high degree of learning of the right words. The changes in them required by the various theories might not have occurred because they were already so favored by the double effect of past learning and familiarity that they were not sensitive to such processes as those supposed to occur. They might have shown reminiscence and supported the maturation hypothesis or have shown forgetting and supported the differential rate hypothesis, had they been at a degree of learning more comparable to the wrong words. Further experiments in this series will investigate this possibility.

Granting for the moment that the high degree of learning of the right words did not prevent these changes from occurring, the results as obtained confirm the conclusion previously arrived at (**7**) that differences in retention of right and wrong responses do not provide as likely explanations of reminiscence and the efficacy of distributed practice as has been generally supposed.[5]

On the other hand the interpretation of reminiscence in discrimination learning as being due to release from performance inhibition will explain the results of the present experiment readily. In original learning the subject is confused because he must confirm (or covertly correct) his last response at the very moment when he must be making his next choice. This confusion results inevitably from the fact that as soon as the reward bell rings, another pair is presented immediately. Such conflict will act to depress the subject's score below what it would be if he were not rushed.

Somehow rest reduces the gap between performance and learning created by the confusion. For example, the conflict might be cumulative. The subject might get behind in his performing, think predominantly of the pair just passed, and guess hurriedly at the pair present. Rest would give him an opportunity to recover from such a cumulative inhibition. Or rest might operate by practicing the subject on the choice reaction since he is required to name colors correctly in the interval. That is, color-naming might serve to emphasize the importance of the pair present rather than the pair just passed, an emphasis which would tend to improve the subject's score. It can only be conjectured just how rest operates. There is

[5] It is recognized that retention of wrong responses and retention of responses to wrong parts of a learning situation are not identical. This means the present experiment is limited as a test of the general differential rate hypothesis. It does not, however, vitiate the conclusion that the hypothesis does not apply here.

ample precedent for assuming that rest does remove inhibition and performance decrements (**12**), but in none of these studies is there evidence as to the mechanism involved. Later experiments in this series will attack the problem.

If it be granted that an inhibition could be so produced and dissipated with rest, how can the fact be explained that the effect was so much greater for the wrong words than for the right words? It has already been pointed out that after the transfer familiarity as well as past learning favored choice of the right words. Transfer made choices from the right word pairs very easy, so easy in fact that probably very little performance difficulty like that in original learning occurred. In the group which rested 6 seconds (the control group) transfer reduced inhibition maximally. Relearning was made as easy as it could be made. The gap between performance and learning was completely closed. Therefore further reduction in inhibition by a 2-minute rest had no added beneficial effect and there was no reminiscence for the right words.

The effect of transfer on the wrong words was just the opposite. It increased the performance difficulties because the subject tended to choose the familiar words, found he was mistaken, and was consequently more confused than ever. Under these circumstances a rest which reduced the inhibition accumulated in original learning was beneficial. The subjects started relearning at a higher level of efficiency, an advantage which made a big difference when the subsequent task was hard (learning the wrong word pairs), and which made little or no difference when the task was easy (learning the right word pairs). Once again, however, the evidence would have been less ambiguous if the difficulty of learning the two kinds of words after the transfer had been the same.

The fact that there is nearly as much reminiscence after a 20-minute rest as after a 2-minute rest suggests that the release from performance inhibition is still effective in improving scores and that forgetting has not yet occurred in sufficient amount to counteract the increased efficiency. The finding is not in accord with that obtained by Ward (**10**) for rote-learning. In his study considerable forgetting had occurred after a 20-minute rest. In the present instance reliable forgetting (relative to the control group's performance) was not obtained even after 24 hours either for the right or wrong words. Apparently forgetting is much less rapid for discrimination learning than for rote-learning.[6] The most likely reason for this is that recognition memory which fades more slowly than reproductive memory (**5**) is required in discrimination learning.

[6] For other evidence of the long retention of discrimination habits, *cf.* Hilgard and Humphreys (**2**).

Summary

Ninety-six subjects learned lists of pairs of adjectives by a discrimination method on two successive days, the first for practice. On the second day they all learned a list until they had reached a criterion of 15 correct choices out of the 20 pairs. Then they were divided into 4 groups of 24, of which one group relearned after a rest of 6 seconds (the usual inter-trial interval), one after 2 minutes, one after 20 minutes, and one after 24 hours. The relearning lists consisted half of right words and half of wrong words from original learning. To complete the pairs a new word was added to each word transferred. Relearning the responses to the right and wrong words under these conditions was measured. The following conclusions appear justified.

In original learning:

(1) The 4 groups of subjects used were of equal learning ability.

(2) They were at comparable points in the mastery of the two sets of pairs from which the wrong words and right words were taken for relearning.

In relearning:

(3) The pairs containing the transferred wrong words were significantly harder to acquire under all conditions than the pairs containing the transferred right words.

(4) The pairs containing the transferred wrong words were easier to acquire after 2-minute and 20-minute rests than they were after a 6 second rest. After a 24-hour interval they were about as hard to relearn as after 6 seconds. These differences were significant when measured by the number of trials taken to reach the same level of learning as was obtained by each subject on the last trial of original learning.

(5) The pairs containing the transferred right words showed no significant or large differences in the ease of acquisition between any of the conditions.

In general the results suggest that the differential in the rate of forgetting of right and wrong parts of a discrimination is more probably due to release from performance decrement than to a more rapid forgetting of errors or to a growth of correct responses. Reminiscence was obtained for the wrong members of the pairs only because they alone were hard enough to learn after transfer to make release from decrement with rest noticeably beneficial.

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A MULTI-PURPOSE LEARNING-DEMONSTRATION APPARATUS

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In teaching the principles of motivation and learning to students of psychology and education, the instructor is likely to find himself handicapped for want of suitable demonstrations. Textbook illustrations and references to the experimental literature are useful in this connection, as are motion pictures; but many teachers find that actual demonstrations, if properly designed, can be still more dramatic and convincing. Animal mazes and problem-boxes of the conventional types, while valuable for research purposes, tend to be bulky and non-portable, to have limited visibility, and to require more time for mastery than is ordinarily available in the classroom. Human learning, on the other hand, can be demonstrated quickly and with minimal apparatus requirements, but it has the important defect of not sufficiently emphasizing the role of motivation. With adult human beings it is almost impossible to use any primary motive satisfactorily, and the secondary motives, being largely of an emotional nature, usually cannot be adequately objectified for instructional purposes. The apparatus here described represents an attempt to evolve a convenient, flexible device specifically adapted for use with rats in a wide variety of classroom demonstrations. Some of these demonstrations will be enumerated after the apparatus has been briefly described.[1]

Details of Construction and Operation

Figure 1 shows front, rear, and end views of this apparatus. The internal dimensions are: length, 34 inches; width, 5 inches; height, 21 inches.[2] The grill, which constitutes the floor, is made of stainless steel rods, 3/32 in. in diameter, placed 3/8 in. apart. The front consists of a piece of double-strength window glass, which can

[1] Duplicates of this apparatus can be purchased, at production-cost, from Mr. Ralph Gerbrands Harvard Psychological Laboratory, Cambridge, Mass.

[2] An apparatus of this height has the advantage of allowing animals to be trained to jump in response to shock or to mechanical signals or oral commands (5) and of preventing them from bumping their heads during exploratory leaps when the shock is being used for other purposes. If however, extreme portability is urgently desired, the dimensions of the apparatus can be reduced by as much as one half.

be removed by opening the top of the apparatus (hinged at the back) and sliding the glass upward. The top and ends are made of ordinary 3/4 in. lumber; the back is made of plywood of the same thickness. The interior of the apparatus is illuminated by two 40-watt showcase

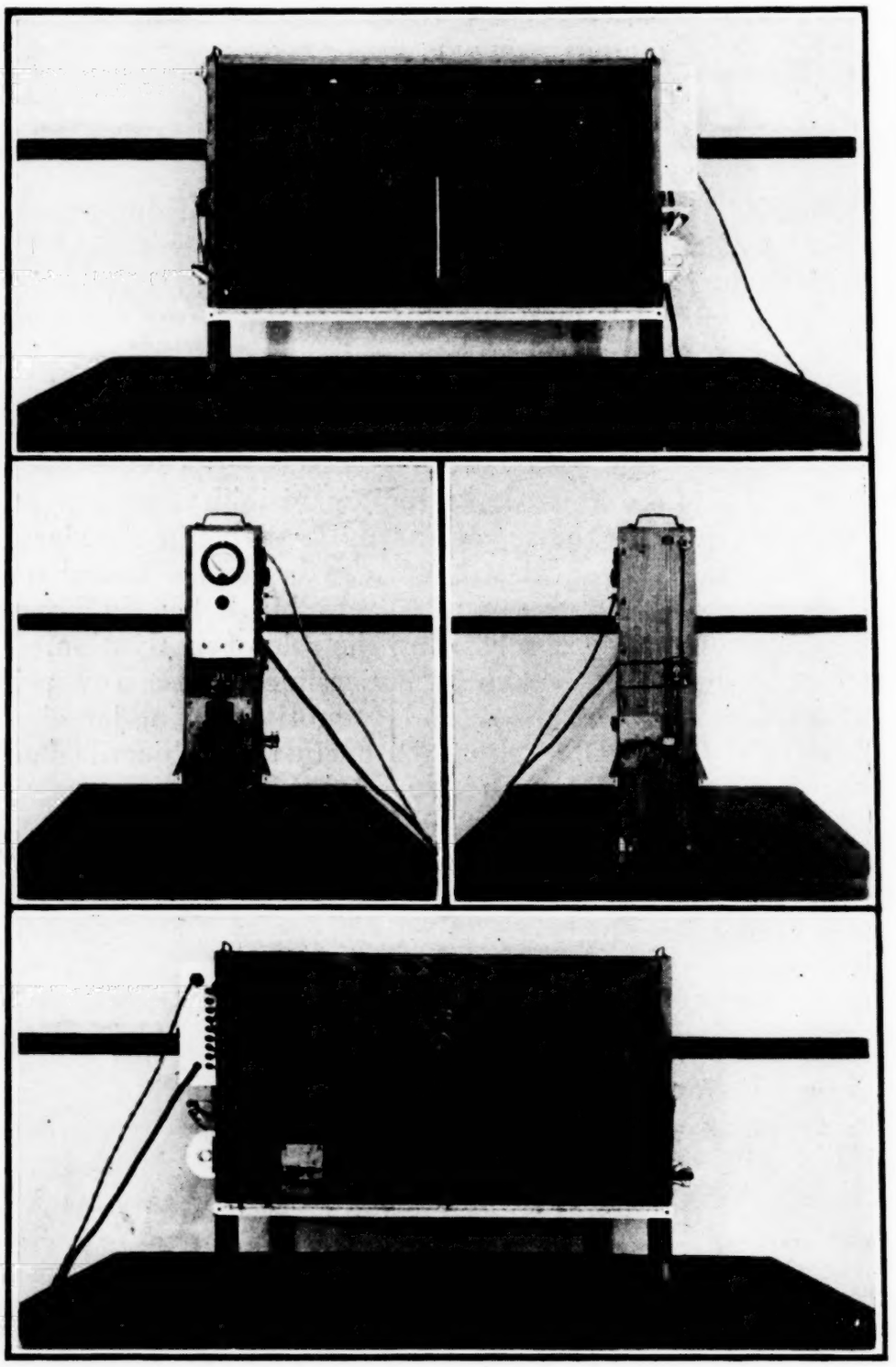

FIG. 1. Apparatus for demonstrating various forms of learning in the rat.

lamps, half silvered in order to reflect more light downward and shield the spectators' eyes.

The diagram shown in Fig. 2 schematically represents the electrical circuits and appliances used in this apparatus. Switches S_2,

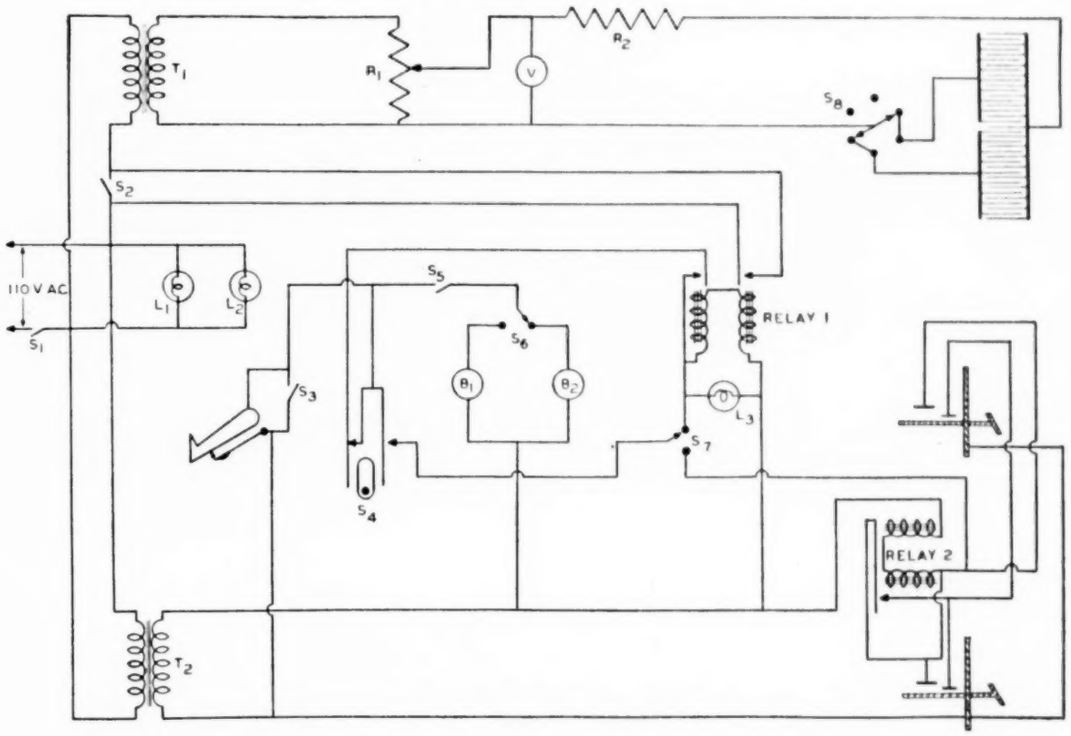

FIG. 2. Wiring diagram of apparatus shown in Fig. 1. L_1 and L_2 are 40-watt Mazda showcase lamps. T_1 is a Thordarson transformer, model T-13R19, delivering 480 volts on the secondary. R_1 is a 50,000-ohm Mallory potentiometer (E-50M-P) while R_2 is a fixed resistor of 350,000 ohms. V is a triplet voltmeter (Model 331), reading from 0–300. S_8 is a Mallory selector switch (3123J). S_3 is a miniature single-pole, single-throw knife switch. S_2 and S_4 are push-buttons. S_6 and S_7 are miniature single-pole, double-throw toggle switches. S_5 is a Mallory jack switch (732) so modified as to make one circuit when rotated clockwise but to break another circuit when rotated counter-clockwise. B_1 and B_2 are an ordinary electric buzzer and bell, respectively. T_2 is a Jefferson bell-ringing transformer (230–101), which delivers 10 volts on the secondary. $Relay_1$ and $Relay_2$ are Dunco Midget double-pole, single-throw relays (RA-3). L_3 is a miniature 10-volt lamp. Other features of the diagram are described in the text.

S_4, S_5, and S_8 (described in the legend) are contained in the remote-control box shown in the foreground of the front view of the apparatus in Fig. 1. This box, which is $4 \times 4 \times 2$ in., is made of steel and is connected with the rest of the apparatus by means of a flexible nine-wire cable. Transformers T_1 and T_2 and $Relay_1$ are located inside a metal chassis, $5 \times 3 \times 8$ in., which is to be seen at the right end of the apparatus. The voltmeter, V, is mounted as shown, with R_1 immediately below and externally adjustable. The apparatus uses no batteries, being energized entirely by alternating current which is led into the apparatus by the extension cord seen in the illustrations.

The electric bell and buzzer, B_1 and B_2, are mounted on the back of the apparatus in the positions shown, with S_6 midway between them. Resistor R_2 is likewise mounted on the back of the apparatus rather than within the metal chassis, in order to make it more accessible. The value of this resistor is, however, fairly critical and should not ordinarily be changed.

The successful use of electric shock in motivating animals on a grill requires a compromise between two equally undesirable extremes. If a low-voltage, low-resistance circuit is used, the amount of current which flows through the animal will be largely influenced by its bodily resistance. This has two disadvantages: it tends to reward posturing behavior, *e.g.*, sitting on the hind legs, which reduces contact with the grill (and thereby increases bodily resistance); and any drop in bodily resistance due to adventitious factors, such as the animal's feet becoming moist, greatly increases the current flow and shock intensity. If, on the other hand, a high-voltage, high-resistance circuit is used, the amount of current flowing through the animal will tend to be constant, regardless of its bodily resistance. Many experimenters have assumed that this was the ideal arrangement since changes in bodily resistance due to variations in skin conductivity or the like do not significantly alter the total current flow. If the area of contact with the grill were constant, this would indeed constitute an advantage; but with a freely moving subject, it is a distinct disadvantage. If the total current flow through the animal's body is constant, variations in the area of contact with the grill necessarily produce changes in *current density*, with attendant variations in strength of stimulation. This inference is supported by the fact that the use of a circuit which passes a relatively constant current through the subject, irrespective of the area of contact with the grill, tends to immobilize the subject. This is due to the fact that with all four feet on the grill the area of contact is greatest and the current density minimal. When the animal runs or otherwise explores about, the area of contact is necessarily lessened, with the result that activity of this kind, so essential to problem-solving, is penalized and discouraged. In order to use an electric grill with good results, it is accordingly necessary to employ (with rats) an intermediate voltage (50–250, depending on the size of the animal and the type of learning required) and a series resistor (R_2) of approximately the value here indicated (350,000 ohms).[3]

As indicated in Fig. 2, either half of the grill can be energized separately, or both halves simultaneously, by properly adjusting selector switch S_8. Actually the current is applied to the grill, once S_8 has been appropriately set, by completing the primary

[3] *Cf.* Wendt *et al.* (9) and Muenzinger and Walz (7).

circuit of T_1, either by closing S_2 or, through $Relay_1$, by turning S_5 momentarily clockwise (which also causes pilot light L_3, on left side of chassis, to glow until the relay is again opened). This arrangement is necessitated by the fact that the grill current has a relatively high voltage and is remotely controlled. The wires enclosed in the cable connecting the remote-control box and the apparatus proper are sufficiently long (about 10 ft.) to permit considerable induction. This means that if T_1 is permanently energized, there is a small but noticeable current on the grill constantly, even though the secondary circuit of T_1 is open. Without this complication, it would not be necessary to employ two transformers, since a single transformer, with multiple secondary windings, could supply both the high and the low voltages needed for the operation of the apparatus.

The mechanical device located on the right end of the apparatus (hereafter referred to as the 'treadmill') acts as a special kind of switch, which is normally closed but can be momentarily opened by revolving the treadmill in the counter-clockwise direction (viewed from the front). The pawl, shown in Fig. 2 in parallel to S_3 and in Fig. 1 immediately above the treadmill, serves a double function: it acts as a ratchet which prevents the treadmill from being revolved clockwise, and it carries a light bronze (silver-tipped) spring which presses constantly against the lower side of the pawl, save when the treadmill is turned. Each time the pawl drops from one transverse bar of the treadmill to the next one, the downward momentum of the spring (made heavier by a small piece of lead) pulls the spring away from the pawl for an instant, thereby breaking the electrical contact between them and opening the lock circuit of $Relay_1$. This special switching arrangement is designed for operation by a rat from within the apparatus. Its somewhat elaborate design is required by the fact that there must be no way in which the circuit can be kept constantly open by the rat, as would be possible with any kind of simple bar or pedal arrangement on which the animal could lean or hang.

Switch S_3, which provides a means of short-circuiting the treadmill and of thereby preventing rotation of the latter from having its usual effect, is located just above the treadmill, as can be seen by close inspection of Fig. 1. By turning S_5 counter-clockwise, the experimenter can produce the same effect by remote control as is achieved by the rat's rotation of the treadmill (*i.e.*, when S_3 is open).

The food-delivery mechanism, mounted at the left end of the apparatus, is shown in Fig. 3.[4] It is activated by the electro-magnet in $Relay_2$, which can be energized by a rat from within the apparatus by pressing a small bar. This bar can be inserted either in the

[4] *Cf.* also Fitts (1), Hanford and Morgan (2), and Skinner (8).

mounting provided near the food box at the left end of the apparatus or in the duplicate mounting located on the back of the apparatus, a few few inches from the right end (see shaded parts of Fig. 2). The double spring contacts which the bar touches when depressed by the rat are used instead of a single contact in order that a complete excursion of the bar will be required to produce each pellet of food. The food-delivery mechanism can also be remotely operated by the experimenter by means of S_5, if S_7 is properly set.

FIG. 3. Escapement mechanism for delivering pellets of food. The pellets are normally held in the magazine (glass tube) by the transverse stop at the lower end. When this is retracted through the action of an electro-magnet (see Fig. 2 and text), the end of the magazine opens and the bottom pellet falls into the food trough below. At the same time the slender curved rod enters the magazine and immobilizes the other pellets. When the transverse stop and the rod return to their normal position, the column of pellets drops by the length of one pellet and the apparatus is again ready to deliver another pellet.

False ends, made of 1/2 in. boards, provide a means of covering the treadmill and the bar and food box whenever this seems desirable.

TRIAL-AND-ERROR LEARNING

The apparatus here described provides opportunities for the development of various habits on a trial-and-error basis. If electric shock is used as motivation, a rat can be taught to shuttle from one to the other (uncharged) half of the grill, to turn the treadmill (which automatically terminates the shock), or to sit on his hind legs, jump into the air, squeal, bite the grill, or do any other act which is in his initial hierarchy of responses to shock and which the experimenter consistently rewards (by turning off the shock). Such habits can usually be taught within 10 to 20 minutes.

If hunger is used as a motive, the subject may be taught to press the bar (which automatically delivers food) or to make any other response that is in the initial hierarchy of hunger-motivated activities, provided again that the experimenter consistently rewards this response (by remotely activating the food-delivery mechanism). For a number of reasons, learning of this type develops more slowly than do shock-motivated habits, but it does not consume so much time as to make it impractical for demonstration purposes.

If a wooden partition with another bar and food delivery mechanism mounted on it is placed in the middle of the apparatus, with the business-end of the bar to the right, two rats, one in the left half of the apparatus and one in the right half, can be demonstrated simultaneously. The contrasting behavior of a hungry and a satiated animal can be shown with especially good effect in an arrangement of this kind.

It is also possible with this apparatus to produce trial-and-error learning by means of secondary motives (emotions). However, the techniques are somewhat complicated, and the reader is consequently referred to an independent discussion of them which has been published elsewhere (**4**).

The gradient of reinforcement can be demonstrated (by delaying reward) in any of the learning situations just described, as can the principle of extinction.

Conditioning and Patterned Learning

Any shock-motivated response, developed on the basis of trial-and-error learning, can usually be conditioned within 10 or 15 trials to the sound of the buzzer (or bell) which is located on the back of the apparatus or to any other type of conspicuous warning stimulus which the experimenter cares to provide. This stimulus should precede the shock by at least three seconds; and the 'instrumental' conditioning procedure (**3**) should always be employed. Once a conditioned response has been established, it can be used to demonstrate sensory generalization, discrimination, and extinction. It is also instructive to carry on trial-and-error learning and conditioning simultaneously, as described elsewhere (**6**).

A hungry rat will learn relatively quickly to come to the food trough in response to the sound of the delivery mechanism or any other stimulus which is consistently followed by the presentation of a pellet of food. This behavior, however, is actually patterned learning, rather than pure conditioning, since what the animal learns is to make a particular response to hunger plus cue stimulus but not to make the response to hunger alone. Pure conditioning

is manifested in this type of situation only if a *satiated* animal responds to the cue, or conditioned stimulus, alone.

Other examples of patterned learning can be provided, for example, by teaching a rat to turn the treadmill to shock plus buzzer but to jump in response to shock alone.

Other Uses

Various forms of conflict, the influence of 'sets' and 'expectancies,' the degeneration of instrumental acts into 'gestures,' social competition and coöperation, and various other psychologically significant forms of behavior can be demonstrated in the apparatus here described. It is likewise valuable, not alone for demonstration purposes, but also, as the writers have found, as a standard piece of research equipment. Students who are permitted to become familiar with its operation and potentialities by actually performing 'practice experiments,' supplementary to class demonstrations, acquire a command of the principles of learning and a sense of conviction as to their power to alter behavior and pattern 'personality' which no amount of reading or lecturing seems to equal.

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A DISCRIMINATIVE SERIAL ACTION APPARATUS

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The apparatus to be described is for the purpose of presenting in a continuing series four color stimuli to which discriminative finger response is made. Correct response to the stimulus brings about immediate and automatic presentation of the next; every response is automatically recorded on high-speed waxed tape, correct responses being distinguishable from incorrect responses on the record. The apparatus may conveniently be considered under four headings: (1) the stimulus box; (2) the response keys; (3) the stimulus selector mechanism; and (4) the recorder.

1. Stimulus Box.—The stimulus box is made of wood painted black, and is 42.5 cm high, 27 cm wide, and 25 cm deep as viewed from the front; a vertical partition divides it into two equal compartments, front and rear. It is attached to a second box 13 cm high, 27 cm wide, and 51 cm deep from which protrude the four response keys, the front surfaces of both boxes presenting a single surface to the subject. In this surface and 13 cm above the keys is a stimulus window formed by a circular hole 2.5 cm in diameter in a metal plate insert in the wooden surface of the box, the hole being backed by ground glass (see Fig. 1).

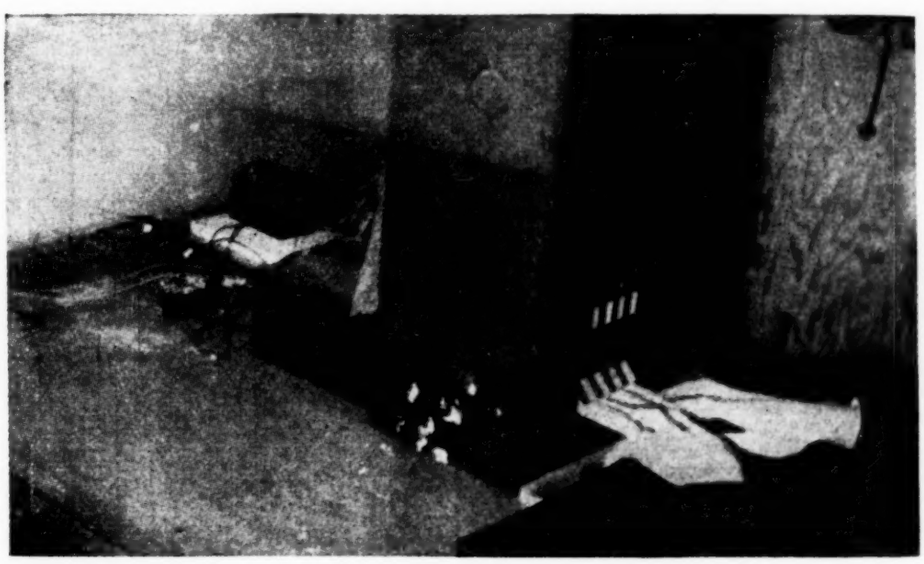


FIG. 1. Stimulus box showing S's fingers in position on keys.

The four color stimuli are produced by 6 watt lamps inside metal housings 8 by 6 by 3 cm. The end surface of each housing is formed by a glass color filter; red, green, blue, and yellow were used. In order to make the blue stimulus equivalent in brightness to the other colors, two lamps and two housings had to be used for the blue. In order to avoid any directional cue from the flashing of the lamps, it is necessary to have the stimulus window lighted uniformly by each color. This is accomplished by mounting the five lamp housings vertically well up toward the top of the front compartment of the stimulus box in one layer of three and one of two at angles in the two vertical planes such that the direction of illumination of each is down past the center of the stimulus window. In addition, a curved metal surface is fitted between angular partitions; it is fastened to the back wall of the compartment near the top of the box, but curves outward toward the bottom so that opposite the stimulus window it curves at an angle of 45 degrees, thus directing the light outward. The entire interior on which illumination falls is coated with aluminum diffusing paint. The combination of angular positions of lamp housings, curved flooring, diffusing paint, and ground glass stimulus window successfully removes directional effects in the illumination of the stimulus window. Figure 2 is a diagram of the front compartment of the stimulus box with the cover removed.

In the rear compartment of the stimulus box are mounted four relays (Dunco, bipolar type) which when closed complete a 110 volt A.C. circuit through the lamps.

2. *Response Keys.*—The four response keys are of maple, painted grey, 1.3 cm wide, 1.9 cm high, and 38 cm long. They are set 1.3 cm apart and protrude 8 cm through slots from the box in which they are mounted. Inside the box is a metal fulcrum on which they rest, with notches serving to keep them in line. Springs attached to the end of each and fastened to the bottom of the box keep them all at equal tension. They can be depressed 1 cm. Each key has on its bottom surface a contact which strikes a corresponding contact in the floor of the box when the key is depressed. The keys are also perforated by plunger contacts which strike metal strips in the floor of the box (completing the interlocking circuit to be described).

Fastened at an angle to the exterior of the box directly above the keys is a metal plate on which are pasted the four stimulus colors, serving as a code to the positions of the keys. Another code is fastened directly below the stimulus window (see Fig. 1).

3. *Stimulus Selector Mechanism.*—The color selector mechanism was adapted from a stepping-switch of a commercial pin-ball machine. It has eighty button-contacts arranged in a circle over which rides a rotating flexible selector arm connected to an eighty-toothed ratchet

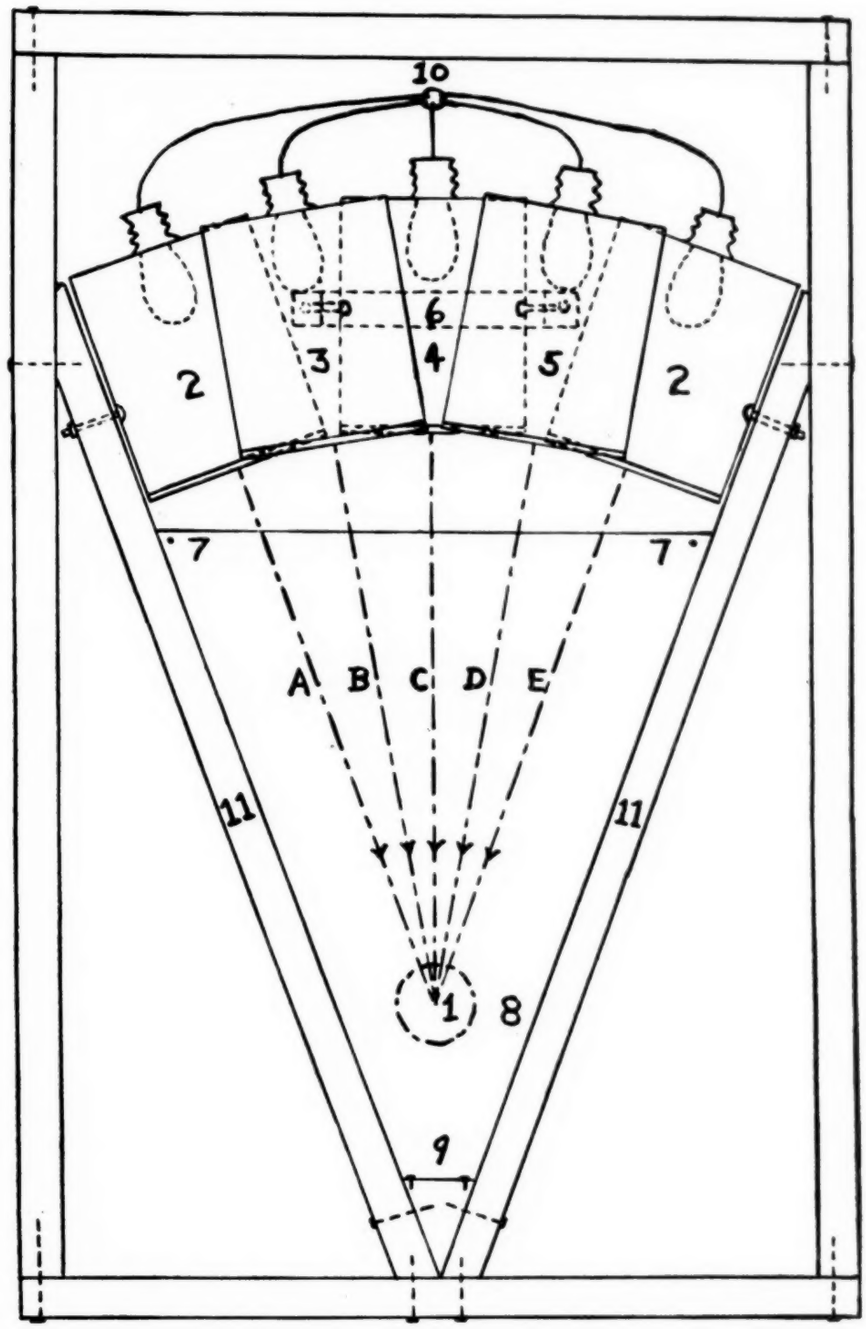


FIG. 2. Diagram of front compartment of stimulus box, with front panel removed (one-third actual size). 1. Position of stimulus window in removed front panel. 2. Lamps, housings and filters for blue illumination. 3. Lamp, housing and filter for yellow illumination. 4. Lamp, housing and filter for green illumination. 5. Lamp, housing and filter for red illumination. 6. Cross-bar and uprights from back wall of compartment for bolting lamp housings in proper angular positions (top of uprights beveled 5 degrees). 7. Metal diffusing surface nailed to back wall of compartment. 8. Metal diffusing surface curving at 45 degree angle from back wall of compartment. 9. Metal diffusing surface curving to level of front panel of compartment. 10. Opening to rear compartment for wires to lamp relays. 11. Angular partitions, extending full depth of compartment. A, B, C, D, E. Direction of illumination.

wheel. Each of the eighty buttons is wired in random order to one of four rings which are wired in turn to the coils of the lamp relays in the stimulus box. A catch connected to the armature of an electro-magnet engages the teeth of the ratchet wheel successively each time the magnet is energized, moving the ratchet wheel one notch each time and causing the selector arm to move from one button to the next. A spring draws the armature back when the magnet is not energized. (The stimulus selector mechanism is placed in a separate room because of the noise it makes.)

4. Recorder.—The recording mechanism consists of a synchronous motor which drives a hard rubber wheel 14.6 cm in diameter. The wheel drives a 300 ft roll of black waxed tape one inch wide at a uniform speed of 103.2 inches per minute; rollers provide traction and keep the tape from slipping. Two magnetic styli, one for right responses, the other for errors, rest on the tape. Resistance coils warm the styli so that their tips melt the wax and trace continuous lines.

Figure 3 is the wiring diagram of the apparatus. When the battery switches are closed, a circuit (18) through the C-battery set is completed, causing one of the lamp relays to close and illuminating the stimulus window with a particular color. Depression of the key corresponding to this color completes a circuit (20A) through the B-battery set, through the key contact, through the closed lamp relay, through the open interlocking relay, and through the coil of the selector relay, thus closing the selector relay. The closing of the selector relay completes two circuits in parallel through the C-battery set, one (19A) through the magnet of the right response stylus, the other (19B) through the selector magnet; it also completes a circuit (21) through the B-battery set, through the closed selector relay, through the locking switch of the selector relay, and through the coil of the selector relay, thus locking the relay closed until the armature of the selector magnet reaches its full extension, at which point a catch trips the locking switch open. (The locking-switch circuit insures a power supply to the selector magnet as long as, but no longer than, is required for it to accomplish the full extension of its armature; this insurance was found to be necessary.) Thus, when the right key is depressed, the right response stylus makes a mark on the moving tape and the armature of the selector magnet moves the ratchet wheel one tooth. As soon as the ratchet wheel moves, the selector arm moves off the button on which it rested, breaking the circuit (18) through the coil of the lamp relay, which opens and extinguishes the lamp; but the circuit is immediately reëstablished through another lamp relay coil as the selector arm

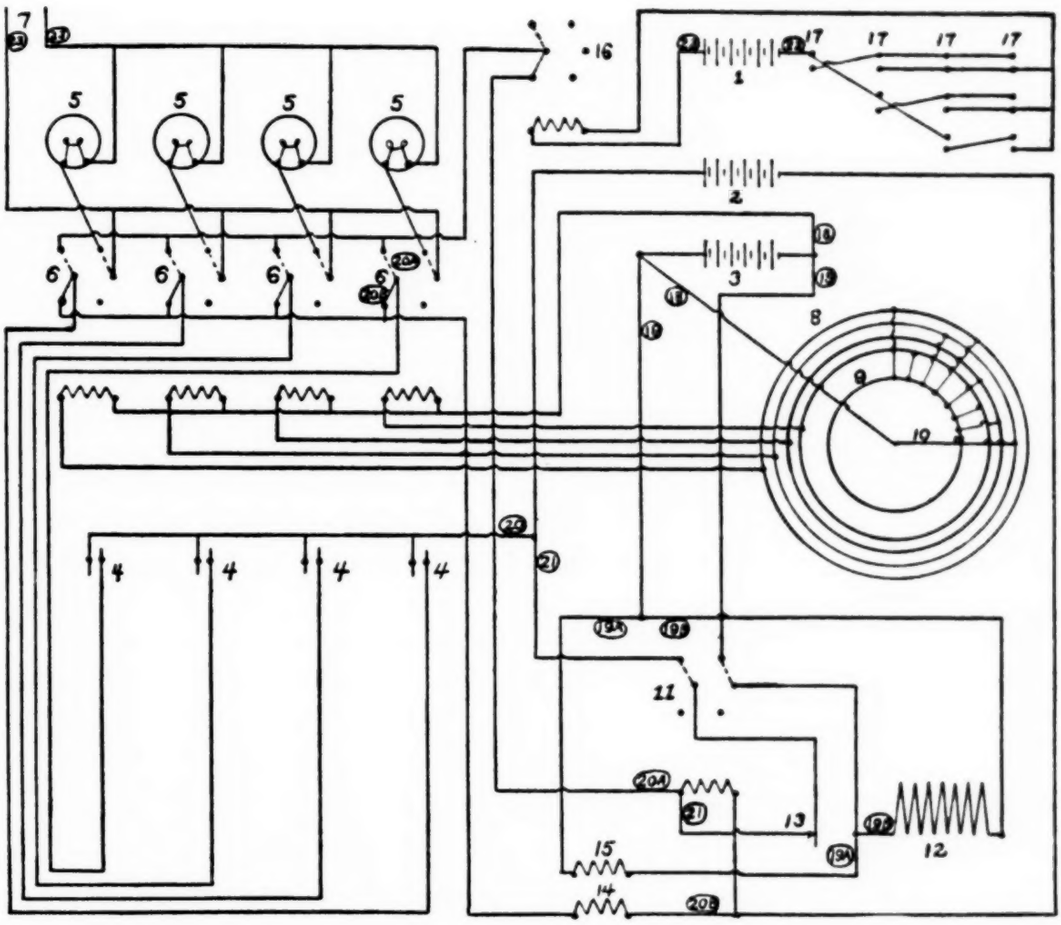
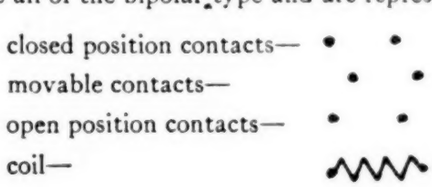


FIG. 3. Key to units (1–17) and circuits (18–23). 1. A-battery set. 2. B-battery set. 3. C-battery set. 4. Response keys. 5. Lamps. 6. Lamp relays. 7. Lines to 110 v., A.C. source. 8. Rings wired to lamp relay coils. 9. Ring of 80 color-selector contacts. 10. Rotating selector arm. 11. Selector relay. 12. Selector magnet. 13. Selector relay locking switch. 14. Error marker magnet. 15. Right response marker magnet. 16. Interlocking relay. 17. Interlocking circuit contacts under respective keys, closed by depression of two or more keys. 18. Circuit through lamp relay coil. 19. Circuit through right response marker magnet (19A), and through selector magnet (19B). 20. Circuit through response key and: selector relay coil if right key is pressed (20A), error marker magnet if wrong key is pressed (20B). 21. Circuit through selector relay locking switch. 22. Interlocking circuit. 23. Circuit supplying 110 v., A.C. to lamps.

Notes

1. Relays in the diagram are all of the bipolar type and are represented as follows:



2. The interlocking circuit contacts in the apparatus are located under the response keys. In the diagram they are placed in a different position from that of the keys for convenience of representation.
3. Regarding circuits 20A, 20B and 21 from the B-battery set, circuit 20A is completed if the lamp relay of the key pressed is closed, and 20B is completed if the relay is open. If 20A is completed, 21 is also completed. If 20B is completed, 21 is not completed.

comes to rest on the next button; the next stimulus is therefore presented.

If a wrong key is depressed, a circuit (20B) through the B-battery set is completed through the key contact, through a particular one of the three open lamp relays, and through the coil of the error stylus, thus causing the error stylus to make a mark on the tape; the selector magnet is not energized, however, and the color does not change.

If two or more keys are depressed simultaneously, the plunger contacts of the keys depressed strike the metal strips beneath the keys and complete the interlocking circuit (22) through the A-battery set, causing the interlocking relay to close. This prevents the energizing of the selector relay coil, and hence the selector magnet and the right response stylus coil are not energized. The error stylus coil is energized, however, and an error is recorded. This action occurs in sequence, since the plunger contacts are set in such a position that they complete the interlocking circuit just before the other contacts on the bottoms of the keys complete the circuit (20B) through the error marker coil. The device of the interlocking circuit insures that the subject does not 'beat the game' by pressing all keys simultaneously. As devised, the apparatus will record a right response and present the next stimulus only if the right key alone is pressed; pressing any other key or combination of keys results in the recording of an error and prevents the appearance of the next stimulus.

The action of the apparatus is quite rapid, so rapid that the error stylus usually makes a mark opposite the right response mark on the tape. This results from the fact that usually before a key can be released, the next lamp circuit has already been established and the key is automatically the 'wrong' key. In reading the tape, of course, all marks on the error line directly opposite marks on the correct response line are disregarded.

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